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Basin analysis and aqueous chemistry of fluids in the Oriskany Sandstone, Appalachian Basin, USA

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Basin Analysis and Aqueous Chemistry of Fluids in the Oriskany Sandstone, Appalachian Basin, USA.

by

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ABSTRACT

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The Oriskany Sandstone of the Appalachian basin is a widely distributed saline aquifer which has produced large quantities of hydrocarbons. Currently the Oriskany is host to numerous gas storage fields and is a potential target for large-scale geologic storage of CO_2. Published and unpublished data of rock characteristics, pressure, temperature, and formation water geochemistry, along with new brine samples were integrated within a geographical information system to better understand the regional-scale hydrogeological regime and its relation to geologic CO_2 sequestration potential. The up-dip flow of the Oriskany Sandstone formation waters is generally controlled by outcrops at high elevation to the east and at low elevation to the west, and opposed by increased salinity-induced buoyancy forces down-dip. The flow pattern is substantiated by the salinity distributions, with relatively lower salinity at recharge to the east and west due to mixing with fresh meteoric water and higher salinity at depth. The Oriskany is generally underpressured, which would aid in sequestering CO_2 by lowering injection and displacement pressures. The geothermal gradient for the Appalachain basin, approximately 20°C/km, is lower than what is expected for cratonic rocks. This could lower the potential for and relative speed of CO_2 migration. Large variations in brine geochemistry, temperature, and pressure will have a major influence on potential for long-term entrapment of CO_2 in the Oriskany Sandstone.

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1 INTRODUCTION

The increasing level of greenhouse gases (GHGs) in the atmosphere is a growing concern as a contributing factor to global climate change. Atmospheric levels of CO_2 have risen significantly from preindustrial levels of 280 parts per million (ppm) to present levels of 384 ppm. Evidence suggests the observed rise in atmospheric CO_2 levels is the result of expanded use of fossil fuels (Tans, 2008). The United States contributes approximately 20% of the world's GHG emissions, most of which is due to the combustion of fossil fuels (5.6 billion metric tons of CO_2 per year; EIA, 2009). Of this amount, 3.8 billion metric tons is from stationary sources, such as power plants, ethanol plants, cement plants, etc. Predictions of increased global fossil energy use during this century imply a continued increase in carbon emissions, and rising CO_2 levels in the atmosphere unless a major change is made in how carbon is managed (EIA, 2009).

Carbon capture and storage in deep geologic formations is one of several carbon management options being studied for reducing anthropogenic CO_2 (Bachu, 2008; Dilmore et al., 2008). This type of carbon management, referred to as geologic storage, involves injecting CO_2 into depleted or near-depleted oil and gas reservoirs, deep coal beds, or deep saline aquifers (USDOE, 1999; Birkholzer and Tsang, 2007; Dilmore et al., 2008). Geological storage technology could be immediately applicable due to the knowledge and experience gained in industries, such as oil and gas exploration and production, natural gas storage, and deep liquid waste and acid gas disposal (Bachu, 2008).

It has been established that the flow of formation waters in sedimentary basins plays an important role in the generation, migration, and accumulation of hydrocarbons (Bachu, 1995b; Anfort et al., 2001; Carr et al., 2005). Also, a better understanding of these regional-scale hydrogeological systems provides a basis to evaluate the potential for long-term containment of CO_2 storage in geologic structures (Carr et al., 2005). Specific technical issues influencing deep CO_2 storage include reservoir pore volume, injectivity, and containment mechanisms. Spatial-variability in brine chemistry, mineralogy, pressure, temperature, porosity, formation extent, and reservoir characteristics is poorly understood (Cook and Benson, 2005; Czernichowski-Lauriol et al., 2006; Bachu et al., 2007; Dilmore et al., 2008). Consequently, storage capacity and potential storage containment time need to be better established on both regional and site-specific scales.

The ideal saline aquifer for geologic storage of CO_2 is comprised of porous rock saturated with brine at sufficient depth to maintain CO_2 in a supercritical condition. It must be capped by one or more regionally extensive impermeable rock formations that enable trapping of injected CO_2 over long periods of time. In addition, areas of converging fluid flow can aid in long-term lateral containment of injected CO_2 (Bachu et al., 2007; Bachu, 2008). A saline aquifer assessed for storage is defined as a porous and permeable body of rock containing water with total dissolved solids (TDS) greater than 10,000 ppm, which can store large volumes of CO_2. A saline aquifer can include more than one named regionally-extensive geologic formation or be defined as only part of a formation (Bachu et al., 2007).

The storage capacity for CO_2 is a geological resource whose availability can be expressed using the resources and reserves concept just as other energy or mineral commodities such as oil and gas, copper, or gold are classified (CSLF, 2005; Bachu et al., 2007). A resource is a commodity whose quantities are estimated to exist at a given time and can be currently or potentially extracted, it can be either in-place or inferred. A reserve is a commodity whose quantities are known to exist and be economically recoverable with current technologies and economic conditions (Frailey et al., 2006; Bachu et al., 2007). This paper attempts to provide improved geospatial data to better evaluate the Oriskany Sandstone as a regional geologic storage resource and to influence future site screening. Site specific evaluations are beyond the scope of this effort and will require additional geologic, geophysical, cultural, and economic data.

More accurate estimates of porosity, salinity, and flow potential of formation water could allow a better estimation of CO_2 storage capacity, as well as indicating possible migration directions, and information on hydrocarbon accumulation (Bachu, 1995b; Anfort et al., 2001; Carr et al., 2005). With the use of both new and existing data, this study has analyzed the Oriskany Sandstone throughout the study area within the Appalachian basin in terms of the parameters that influence storage resource volume, injectivity, and long-term containment. The often significant differences (i.e. depth, thickness, salinity, pressure, temperature, and porosity) that exist across the extent of the Oriskany Sandstone have been taken into account. This study has estimated the salinity, large scale potential flow of the formation water, and basin-scale storage resource volume of the Oriskany Sandstone.

1.1 BACKGROUND INFORMATION

The concept of separating CO_2 from flue gases and storing it away from the atmosphere emerged in the late 1970's, and research and development into CO_2 storage began in the early 1990's (Cook and Benson, 2005). Carbon capture and storage has become a promising option for reducing CO_2 emissions in the past decade (Benson, 2005). Three main forms of CO_2 storage have been identified: surface mineral carbonation, in oceans, and in deep geological media (IPCC, 2005). Of these three options, only deep geological storage could be immediately applied due to knowledge and experience gained in the oil and gas and deep liquid disposal industries (Bachu, 2008). Deep geological storage has a large estimated capacity, although unevenly distributed worldwide, and has the potential retention time of centuries to millions of years (IPCC, 2005; Bachu et al., 2007).

Storage of CO_2 within geological media is possible through a combination of physical and chemical trapping, know as hydrodynamic trapping, that operate over different time frames (IPCC, 2005; Bachu et al., 2007) (Figure 1-1). Physical trapping is when CO_2 is immobilized as a free gas or supercritical fluid (Bachu, 2008). Two types of physical trapping exist: (1) static trapping in stratigraphic and structural traps, much like natural gas is trapped under a low-permeability cap rock in gas reservoirs; and (2) residual-gas trapping as a residual, not-wetting phase in the pore spaces of the rock. Chemical trapping occurs when CO_2 dissolves in subsurface fluid, which is referred to as solubility or ionic trapping. The dissolved CO_2 can then react directly or indirectly with the rock matrix or formation waters and form carbonate minerals, this process is known as mineral trapping (Benson, 2005; Bachu et al., 2007). Static trapping is the most important mechanism during and immediately after CO_2 injection (Benson, 2005). Residual-gas, solubility and mineral trapping mechanisms operate over a longer time scale, but play a vital role in increasing the safety and security of CO_2 storage after injection has ceased (Bachu, 2008). The volume and efficiency of long-term trapping of CO_2 within geologic media is strongly influenced by the temperature, pressure, and geochemistry of the fluid and rock matrix.

Sedimentary basins are the most probable location for geological CO_2 storage. The deposits here are typically up to many thousands of meters thick and consist of alternating layers of sandstone and shale. Permeable and porous layers, typically sandstone or limestone, are candidates for storage reservoirs, with porosity needed for storage capacity and higher

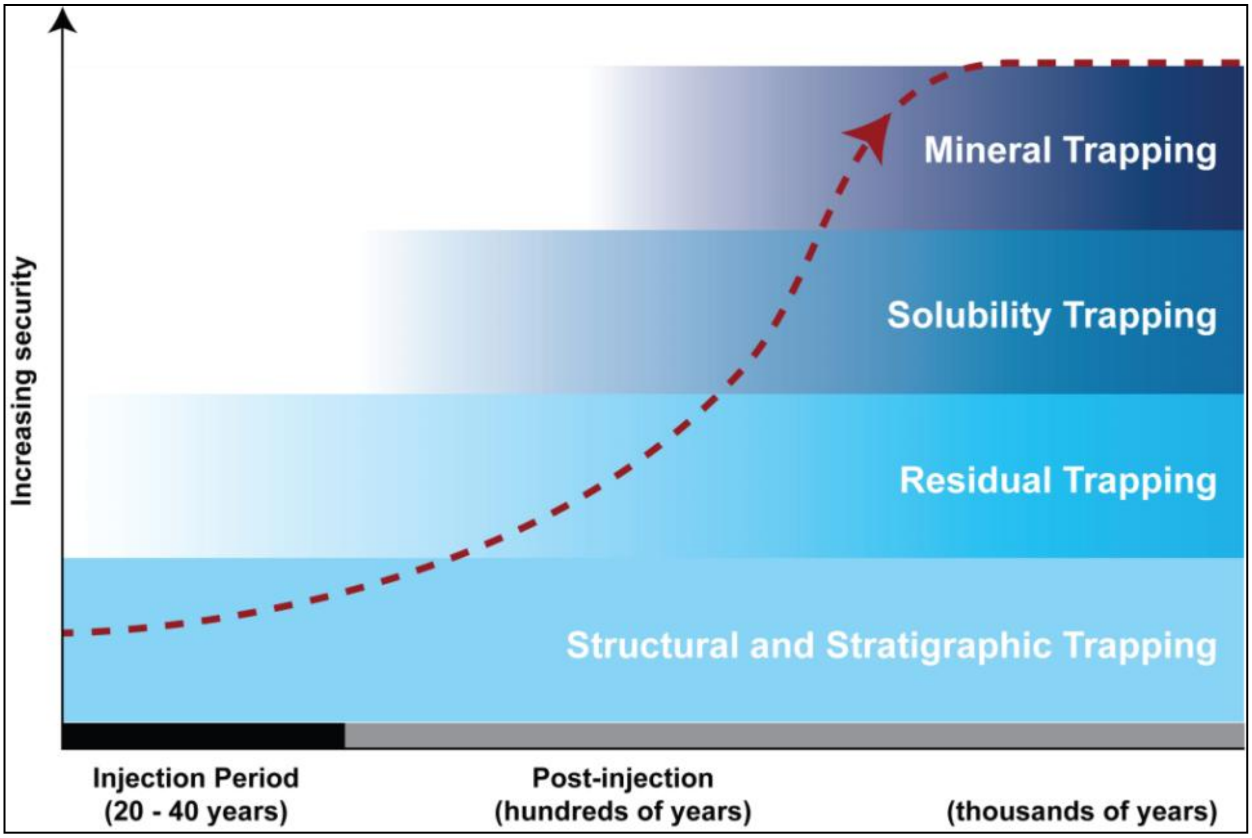

Figure 1-1. Approximate time frame for various physical and chemical trapping mechanisms involved in CO_2 sequestration. Source: http://www.co2crc.com.au/images/geopics/trappingsecurity.jpg

permeability allowing CO_2 injection. Overlying shale or evaporite layers of low permeability are potential seal zones to prevent CO_2 escape to the surface (Benson, 2005; Bachu, 2008). Within sedimentary basins three categories of geological media are considered as potential storage sites for CO_2 (Bachu et al., 2007): (1) oil and gas reservoirs; (2) deep coal seams; and (3) deep saline aquifers.

Deep saline aquifers, as defined by Bachu et al. (2007), contain water of total dissolved solids (TDS) greater than 10,000 mg/L and are present in most sedimentary basins worldwide. The deep saline aquifers have the largest potential storage resource capacity of all geologic media considered as suitable storage sites, and are an immediately-available prospect for geological CO_2 storage (Cook and Benson, 2005; Bachu et al., 2007; Bachu, 2008). However, less is typically known about deep saline aquifers because they lack sufficient subsurface data, causing uncertainty regarding its suitability for CO_2 sequestration (USDOE, 2007). The storage capacity of such aquifers and the potential storage containment time need to be established on regional as well as site-specific scales.

Specific-technical issues influencing deep CO_2 storage include trapping mechanisms, as well as spatial-variability in brine chemistry, mineralogy, pressure, temperature, porosity, permeability, formation extent, and reservoir characteristics (Cook and Benson, 2005; Czernichowski-Lauriol et al., 2006; Bachu et al., 2007; Dilmore et al., 2008). Potential saline aquifers must meet four basic criteria for CO_2 sequestration. (1) The temperature and pressure conditions must be adequate to keep the injected CO_2 in the dense supercritical or liquid phase (at the critical point for CO_2 the temperature T_c is 31.1°C and P_c is 7.83 megapascals, or MPa an approximate depth of 800 meters; Figure 1-2). (2) The aquifer must have adequate permeability and porosity for injectivity. (3) An adequate seal must be present to provide vertical containment

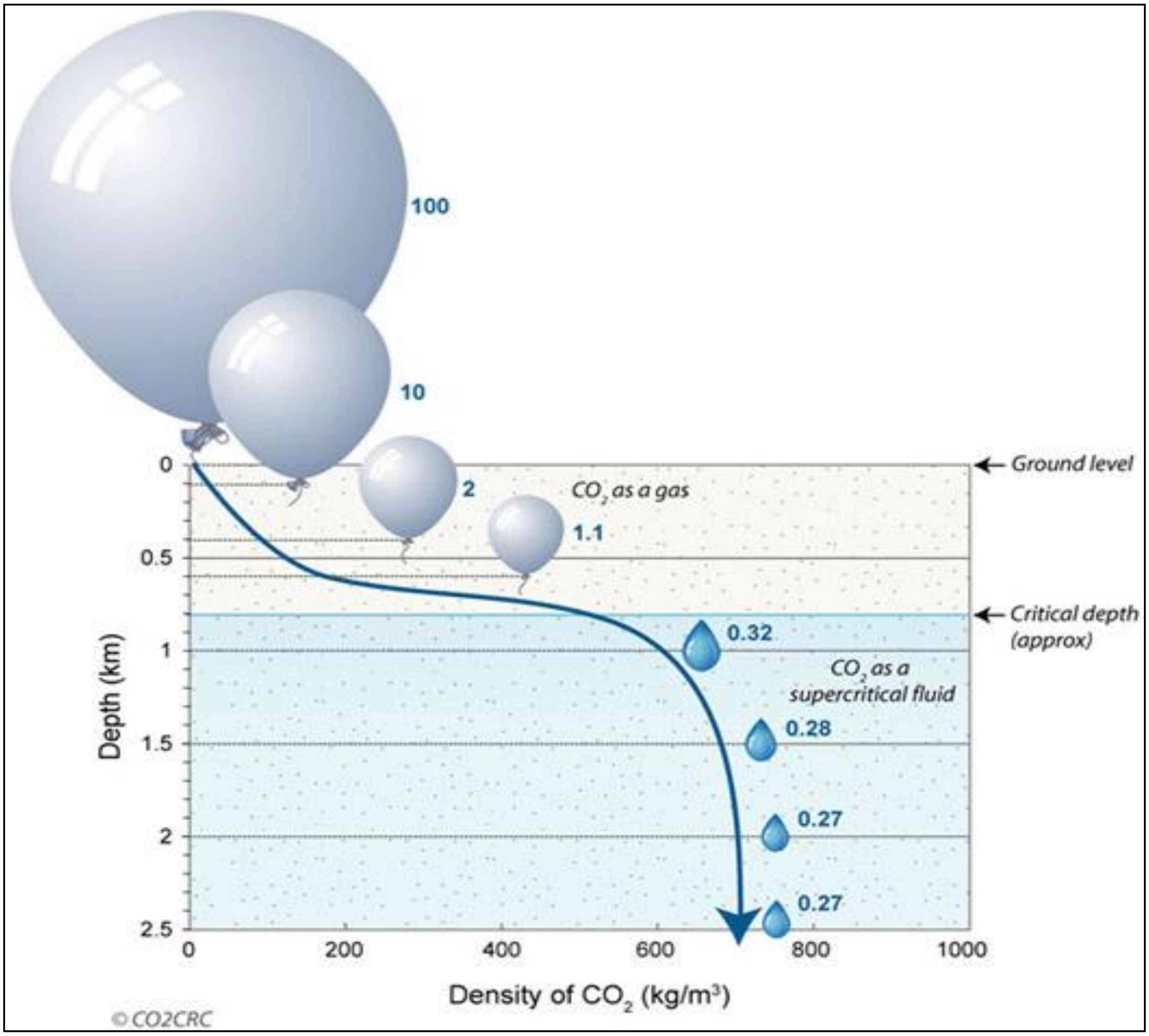

Figure 1-2. At depths greater than 800 meters, injected CO_2 is a supercritical fluid. Source: http://www.wvcarb.org/cc-overview.php

and limit flow of CO_2 to the surface. (4) The TDS should be more than 10,000 mg/L, the approximate upper limit of potable drinking water (Bachu et al., 2007; USDOE, 2007; Bachu, 2008).

1.2 GEOLOGIC SETTING AND REGIONAL STRATIGRAPHY

The Appalachian basin (Figure 1-3) is approximately 500 kilometers (km) wide and 1,000 km long and encompasses a broad area between the Canadian Shield to the north, the Allegheny front to the east and the Cincinnati arch to the west (UTBEG, 2008). It represents part of an ancient foreland basin in the eastern United States that contains complex geology formed by a series of continental plate collisions. This deformation resulted in the formation of the Appalachian Mountains and large areas of stretched, faulted, and deformed ridges and valleys (USGS, 2008; UTBEG, 2008). The elongate, asymmetrical northeast-southwest trending central axis of the Appalachian basin is underlain by a succession of strata greater than 3,000 meters thick (UTBEG, 2008). Overlying a major interregional unconformity in the Appalachian basin is the Oriskany Sandstone, a widespread gas reservoir and saline aquifer (Deicchio, et al., 1984).

The Oriskany Sandstone of the Appalachian basin represents the Deerpark stage of the Early Devonian (Diecchio, 1985). The Oriskany Sandstone was named by Vanuxem (1839) for its type locality in Oriskany Falls, Oneida County, New York. At this location, the Oriskany is a white, fossiliferous quartz arenite (Opritza, 1996; Patchen and Harper, 1996). Most of the studies done on the formation before 1930 were for purposes of clarifying the stratigraphic and paleontological relationships of Lower Devonian and Upper Silurian rocks (for example, see

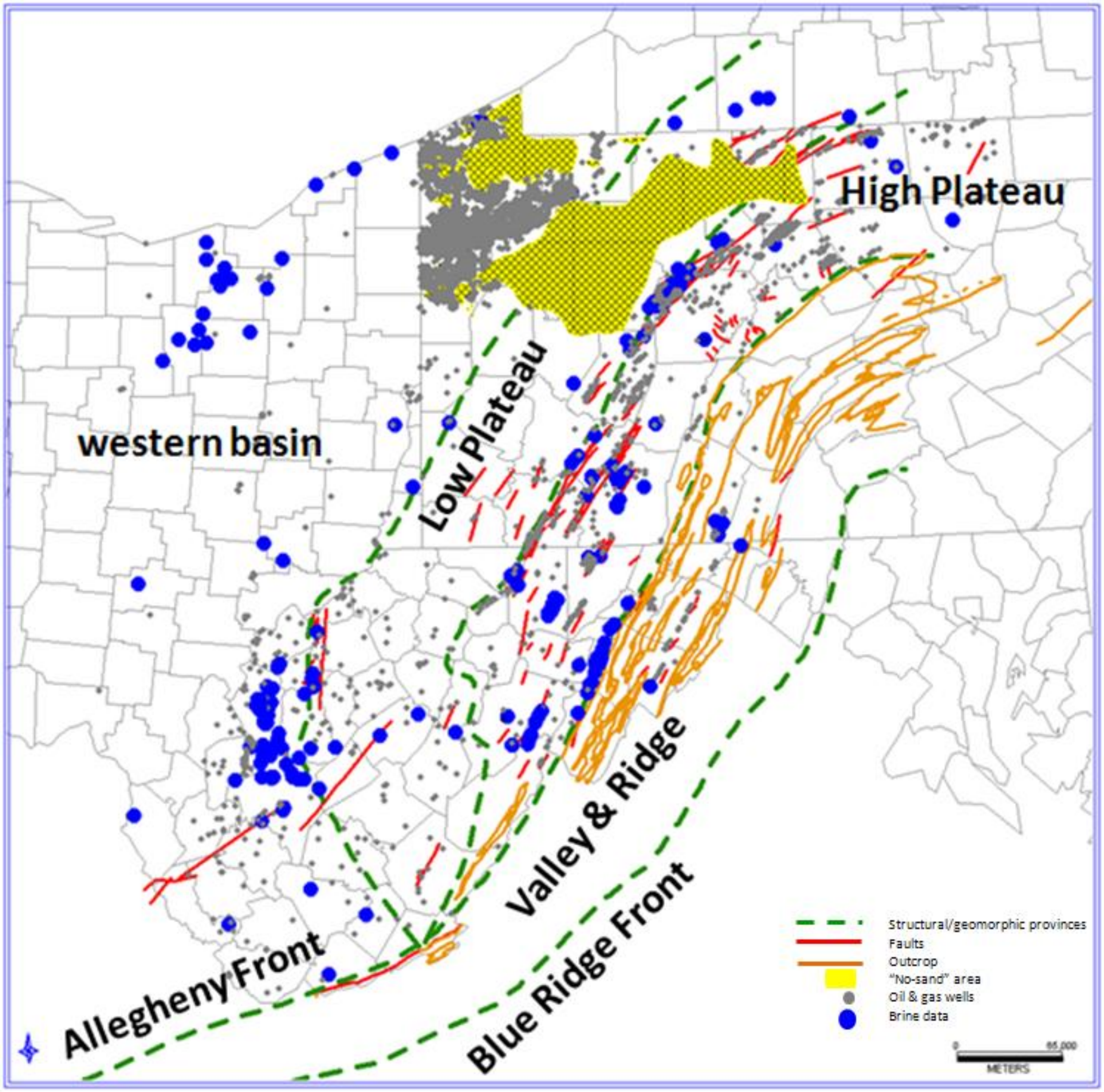

Figure 1-3. Study area within the Appalachian basin that includes the states of Maryland, New York, Ohio, Pennsylvania, and West Virginia. Green dashed lines indicate the Appalachian basin structural/geomorphic provinces of Diecchio (1985). Red lines indicate faults within the Oriskany Sandstone (MRCSP, 2008). Orange lines depict area of known Oriskany outcrop (MRCSP, 2008). Yellow hatched polygons indicate areas of "no-sand" (Diecchio, 1985). Small gray circles are oil and gas wells with data. Large blue circles indicate wells with brine data.

Swartz, 1913). However, since 1930, the Oriskany has become one of the most important formations for gas exploration and gas storage in the Appalachian basin. As a result, the Oriskany has been the subject of numerous studies related to structure, stratigraphy, petrology, petrophysics, and other topics (Diecchio et al., 1984; Deicchio, 1985).

The Oriskany is typically a fossiliferous quartzarenite cemented with locally-variable amounts of quartz or calcite. It can be traced continuously through New York, Pennsylvania, Ohio, Maryland, West Virginia, Virginia, and Kentucky (Diecchio, 1985; Bruner and Smosna, 2008). The Oriskany typically unconformably overlies strata of the Helderberg Limestone or equivalents, and is overlain by Onondaga Limestone, Huntersville Chert, or Needmore Shale (Figure 1-4), which vary from limestone to chert to shale and are locally sandy (Diecchio, 1985). Since the Oriskany is a major deep gas producer within the basin, data such as pressure, temperature, porosity, permeability, and brine composition are available (Diecchio et al., 1984). The data indicate that there exists intergranular and fracture porosity within the Oriskany, and overlying thick low-permeability zones within the Appalachian basin provide the potential for vertical containment (Diecchio, et al., 1984; Gupta et al., 2005).

The Oriskany commonly has been considered to be overpressured because of initial open flow pressures in some areas of the basin as high as 31,026 kiloPascal (kPa) (Wickstrom et al., 2005). However, pressure/depth ratios range from 5.13 to 16.70 kPa/m, averaging 9.92 kPa/m, which is close to the normal hydrostatic pressure gradient for freshwater. Russell (1972) suggested that, on average, the Oriskany is not an overpressured reservoir, and that overpressuring is more common in areas of intense deformation. Patchen and Harper (1996), however, indicate that the more highly deformed areas, such as south-central Pennsylvania, western Maryland, and eastern West Virginia, tend to have abnormally underpressured

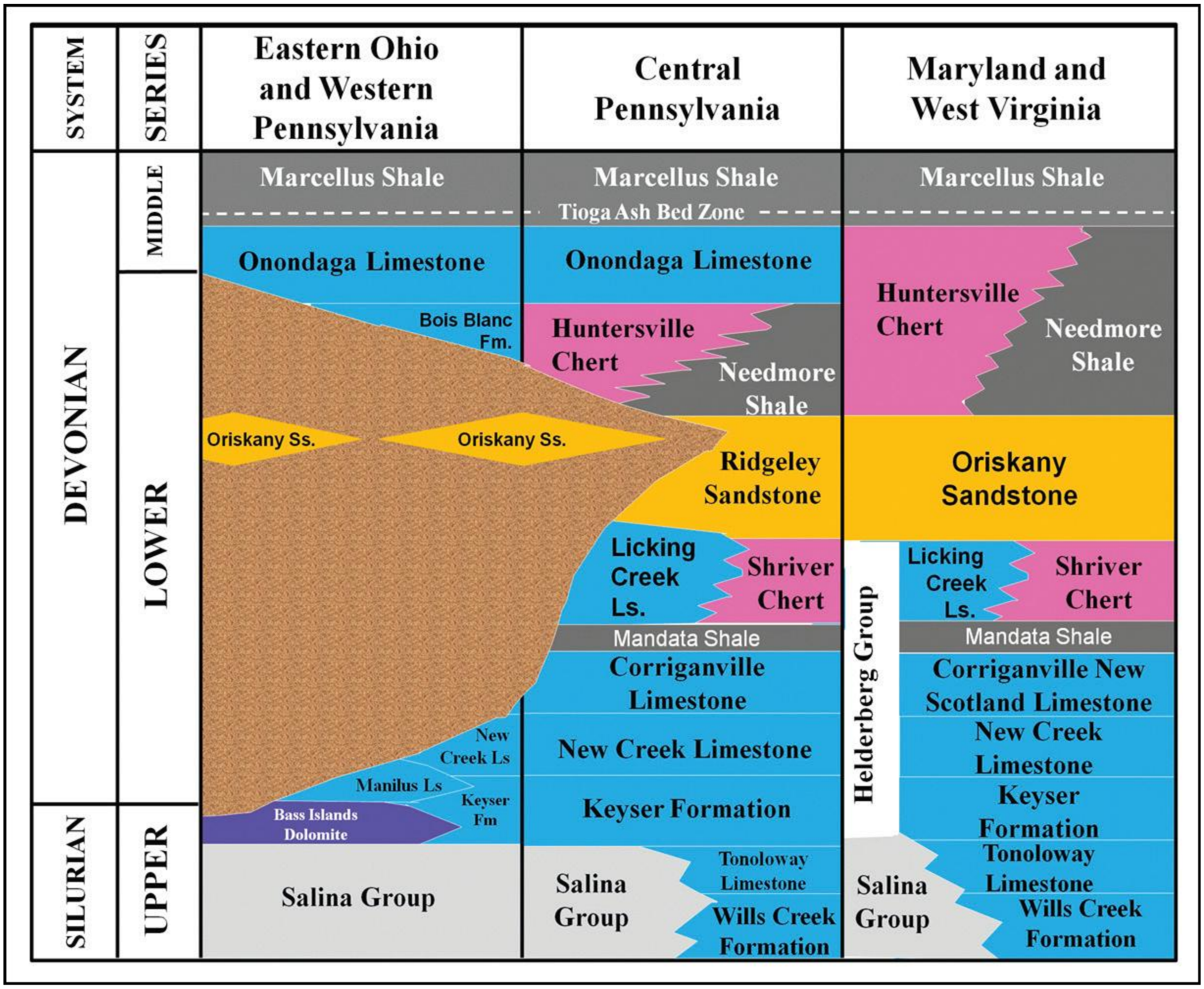

Figure 1-4. Stratigraphic column of Lower Devonian of Maryland, Ohio, Pennsylvania, and West Virginia. Based on stratigraphic column of Pennsylvania Geological and Economic Survey.

reservoirs. Pressure-depth rations in this area range from 5.78 to 11.25 with an average of 8.84. In contrast, pressure-depth ratios in the "less deformed" areas of western Pennsylvania and south-central New York range from 5.13 to 16.70, averaging 10.33. The relationship of degree of deformation to pressure gradient is not readily apparent but might be due, at least in part, to the ability of the reservoir to maintain fluids following intense fracturing. Brines in the Oriskany Sandstone have been reported to have very variable salinity values, often ranging into the 200,000 to 350,000 ppm range, and a wealth of varied chemistries (Kelley et al., 1973). The highest values are for chloride, followed by sodium and calcium. Smaller but significant concentrations of magnesium and bromide also commonly occur.

1.3 PREVIOUS INVESTIGATIONS

The Oriskany Sandstone has been analyzed recently by the USDOE to determine its CO_2 sequestration reservoir potential (Soong et al., 2004a, 2004b; Dilmore et al., 2008). These studies of the solubility and displacement volumes for CO_2 sequestration potential were based upon brine samples taken from a single well in Indiana County, Pennsylvania and samples from a single well were assumed to be representative of Oriskany Formation brine chemistry basin wide (Dilmore et al., 2008). Due to varying depth, thickness, porosity, temperature, pressure, and brine composition, additional analyses over a more extensive area are needed in order to properly characterize the Oriskany saline aquifer. Each of these variables independently has the potential to affect the volume and long-term retention of CO_2 that could be injected and/or stored.

At standard atmospheric conditions CO_2 is a stable gas that is slightly denser than air. For temperatures greater than 31.1 °C and pressures greater than 7.38 MPa, CO_2 is a supercritical fluid. In its supercritical state, CO_2 has the high-density characteristics of a liquid yet behaves like a gas by filling all the available volume (Bachu and Stewart, 2002; Bachu 2008). In order for the injected CO_2 to remain in a supercritical phase, the Oriskany Sandstone must be 800 meters or greater in depth. Maintaining this supercritical phase is important because the injected CO_2 occupies several orders of magnitude less volume than in its gaseous phase. These deep depths will also reduce the relative buoyancy of the CO_2 and help to insure an adequate thickness of confining layers is present above the Oriskany to act as an impermeable seal.

Estimating the porosity and thickness of the Oriskany will provide a means to calculate the reservoir's potential volume that can be used to store CO_2 when the depth criterion is taken into consideration. The average porosity value controls the maximum possible space that the sequestered CO_2 can occupy. The brine composition of the aqueous fluids within this porosity is critical for determining the volume of CO_2 trapped through dissolution into the formation water and precipitated as mineral components. The solubility of CO_2 in the formation water decreases with increasing water salinity (Brennan and Burruss, 2006).

1.4 OBJECTIVES

1.4.1 BASIN FRAMEWORK

The geology, stratigraphy, and geometry of the Oriskany were described to assist in approximating the flow regime and volume estimation. Well data was processed using a subsurface geologic information system (Petra™), to generate structure contour maps, isopach maps, and grids for calculating CO_2 storage volume.

1.4.2 ROCK PROPERTIES

The porosity of basin rocks is a hydraulic property that has control on the subsurface fluid flow (Bachu and Undershultz, 1992). Core- and well-scale porosity were used to estimate the basin (regional) scale porosity of the Oriskany. The well-scale porosity is the vertical arithmetic average of the core-scale values weighted by the thickness of the uniter sampled. The basin (regional) scale estimates were obtained from the large-scale spatially averaged well-scale porosity.

1.4.3 FLOW AND CHEMISTRY OF FORMATION WATER

Knowledge of sedimentary basin geology, lithology, and hydrostratigraphy is important in understanding the flow of formation waters (Bachu and Undershultz, 1995; Bachu, 1997). Fluid flow is driven by fluid pressure gradients, which may be influenced to greater or lesser degrees by compaction, topographic variations in water column height, pressure loss to flow, and spatial variations in temperature, pressure, elevation, density, and fluid composition (Bachu, 1995a). Spatial variations in temperature, pressure, density, and TDS concentrations were mapped across the basin. All data used in this study is available on the West Virginia GIS Technical Center website http://wvgis.wvu.edu.

2 BASIN FRAMEWORK

2.1 METHODOLOGY

The geology, stratigraphy, and geometry of the Appalachian basin have been described to assist in approximating the potential flow regime. Latitude, longitude, elevation, and depth to formation data was obtained from drilling records available from the Maryland, Ohio, Pennsylvania, and West Virginia Geological Surveys, as well as participating oil and gas companies. The elevation and depth values were expressed relative to sea level. The data was processed and the resulting grids and maps were checked for internal consistency. The processed data was used to generate a structure contour map, a depth map and an isopach map using the minimum curvature gridding parameters. Using a minimum depth of 800 meters the potential sequestration area within which CO_2 would be supercritical in the Oriskany was determined. The produced grids were used to estimate the basin volume needed to calculate potential CO_2 storage volume.

2.2 RESULTS

2.2.1 STRUCTURE CONTOUR

The Oriskany Sandstone forms dips toward the center of the Appalachian basin along a northeast-southwest trend (Figure 2-1). At the center of the study area, it reaches a maximum depth ≤ 2,000 meters mean sea level (MSL). It shallows towards outcrop areas to the east (along the Allegheny Front and Eastern Overthrust Belt) and west (Cincinnati Arch). The area within the known outcrop belt could not be accurately represented with the limited data and therefore was not contoured.

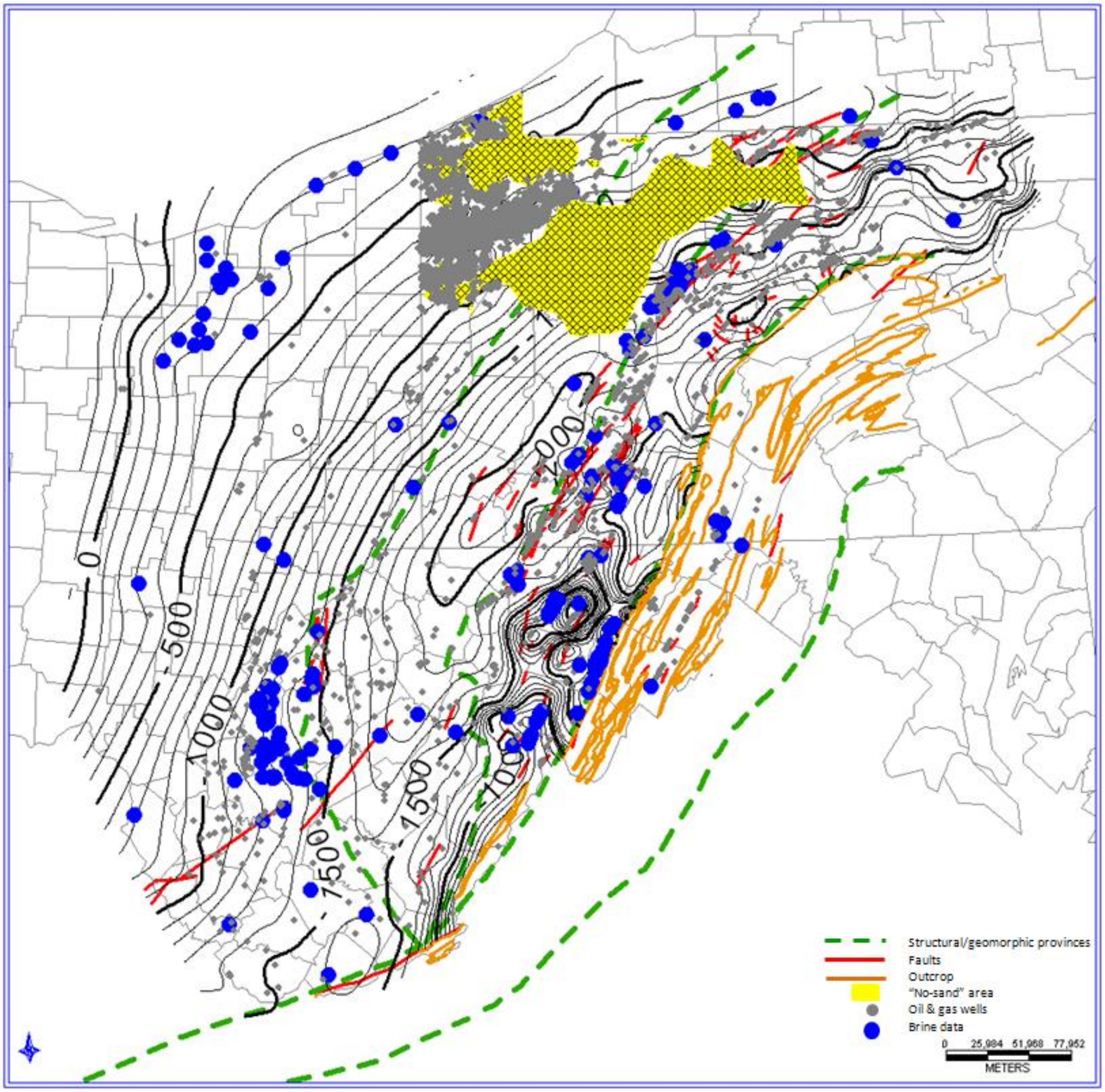

Figure 2-1. Structure on the top of the Oriskany Sandstone. Contour interval is 100 meters.

2.2.2 DEPTH

A map of depth to the Oriskany was constructed to map areas suitable for supercritical CO_2 injection. The Oriskany reaches maximum depths of over 2,500 meters the center of the Appalachian basin (Figure 2-2). Potential CO_2 sequestration area was mapped along the 800 meter depth contour (Figure 2-3). The area was not mapped into locations were depth data were lacking. The delineated area is 139,000 km^2 (± 1,000 km^2).

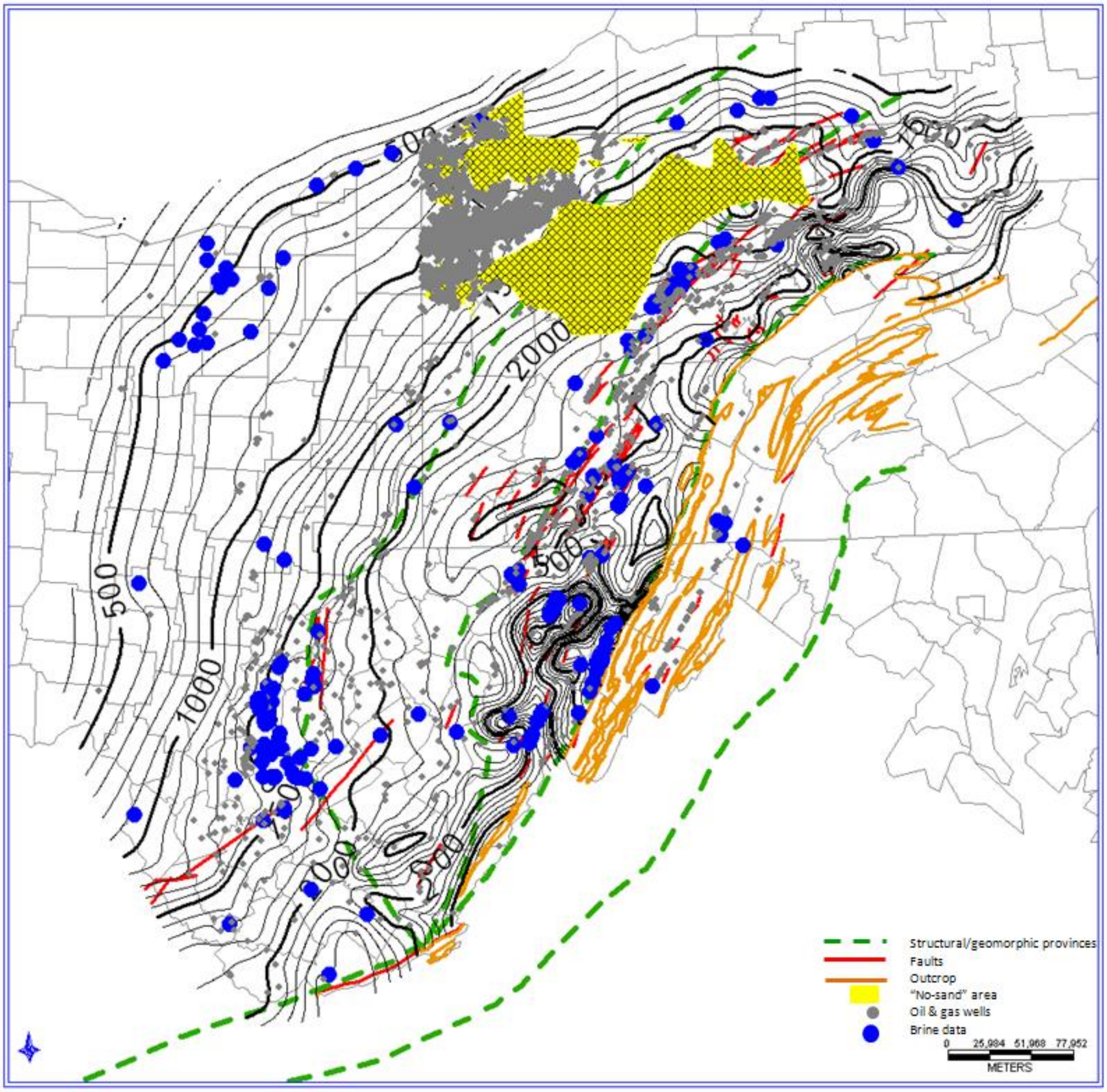

Figure 2-2. Depth to top of Oriskany Sandstone. Contour interval is 100 meters. Areas within the know outcrop belt to the east were not contoured due to lack of sufficient data to accurately depict the complex structure.

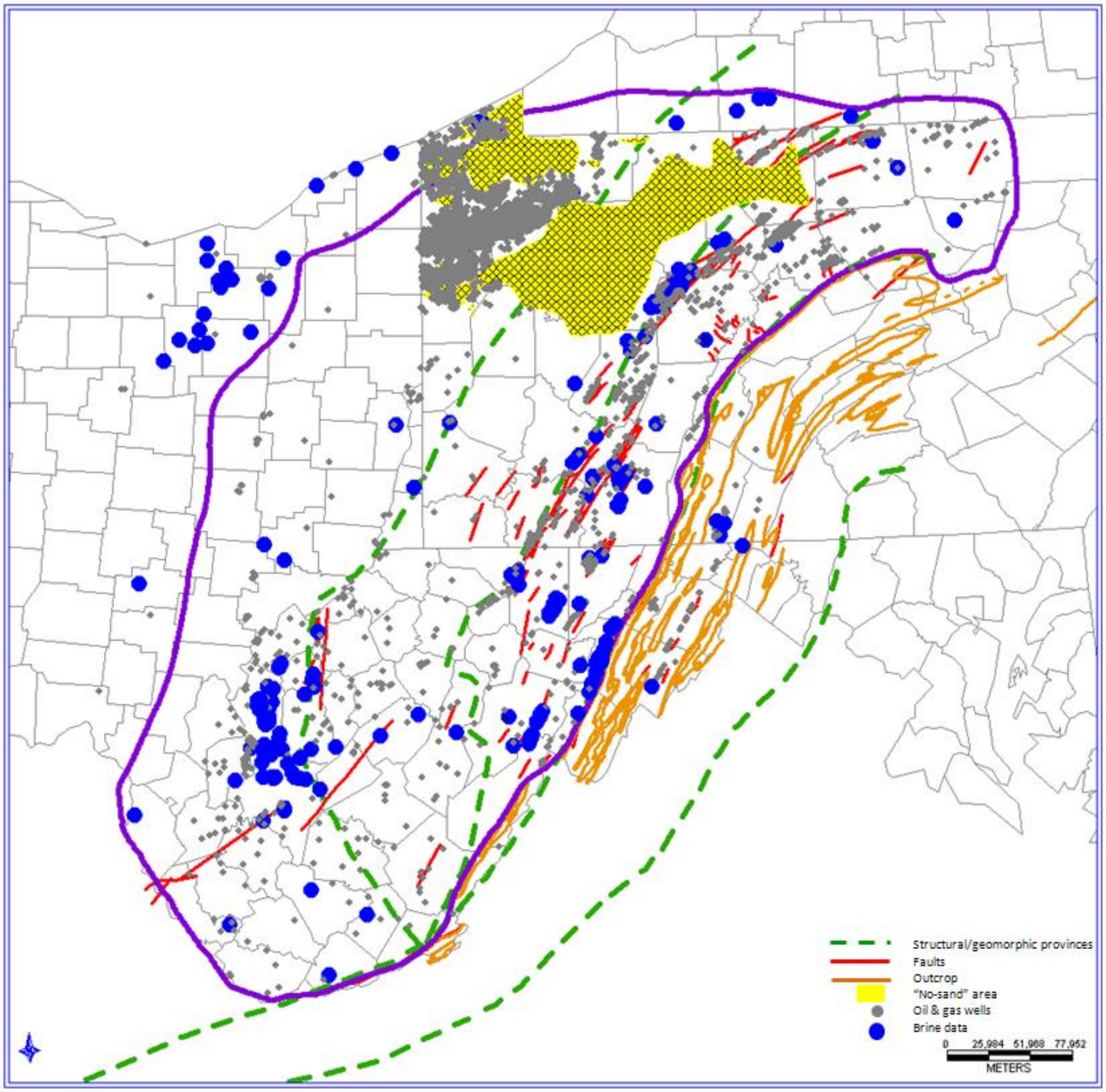

Figure 2-3. Oriskany Sandstone potential sequestration area. The purple line indicates the study area that meets the depth greater than 800 meters criteria for supercritical CO_2 storage and avoids areas of known outcrop belts.

2.2.3 ISOPACH

The thickness of the Oriskany varies across the Appalachian basin from zero to a thickness ≥ 75 meters (Figure 2-3). In the "no-sand area" in the northern Appalachian basin, the Oriskany is thin or absent due to erosion or non-deposition (Diecchio, 1985). The Oriskany is typically thickest in the High Plateau and Eastern Overthrust Belt regions, but thins and pinches out to the west, northwest and south, where it is generally ≤ 10 meters thick.

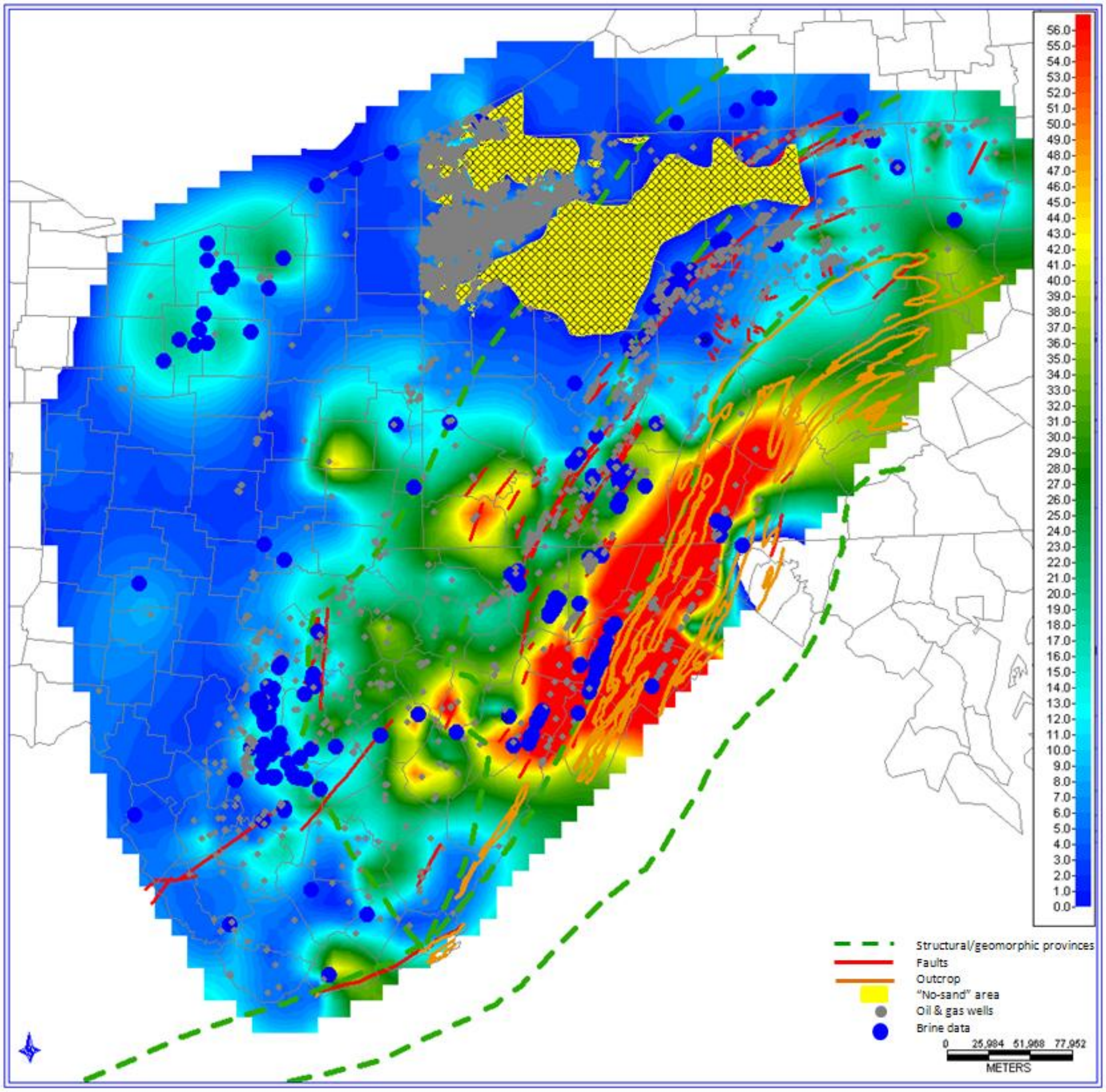

Figure 2-3. Oriskany Sandstone thickness estimate. The average thickness is 16 meters. Contour interval is 1 meter. "No-sand areas" are indicated by yellow cross-hatched.

3 **ROCK PROPERTIES**

3.1 METHODOLOGY

Previously-analyzed core data were used to estimate the porosity of the Oriskany. The data were largely restricted to areas of existing oil and gas wells, requiring extrapolated across data gaps to map the study area. The core scale porosity measurements were scaled up to well scale and then to basin scale using the method described by Bachu and Underschultz (1992, 1993). The method states that the formation-scale porosity index (Φ) of the unit is the arithmetic average of the core-scale values weighted by the thickness of the unit. Since reported core porosity data represent volume-averaged values corresponding to the physical size of the sample (i.e., core plug), it does not reflect larger scale secondary porosity elements such as vugs and fractures (Bachu and Undershultz, 1992). The value was then be used to estimate the potential CO_2 storage volume.

3.2 RESULTS

Porosity estimates were collected from published studies, as well as from producing or potential oil and gas wells (Headlee and Joseph, 1945; Herald, et al., 1962; Harper and Patchen, 1996; New York Geological Survey; and Texas Keystone; Table 1). These data consisted of 19 porosity values, for counties and individual oil and gas fields. These porosity values were assigned to the wells located within the counties or fields resulting in a total of 894 well values. Using the method of Bachu and Undershultz (1992, 1993) a mean porosity of 8.08% was estimated and a map was interpolated using the minimum curvature method with Petra™ (Figure

3-1). The Low Plateau and High Plateau of the central Appalachian basin contain the area with the lowest porosity values.

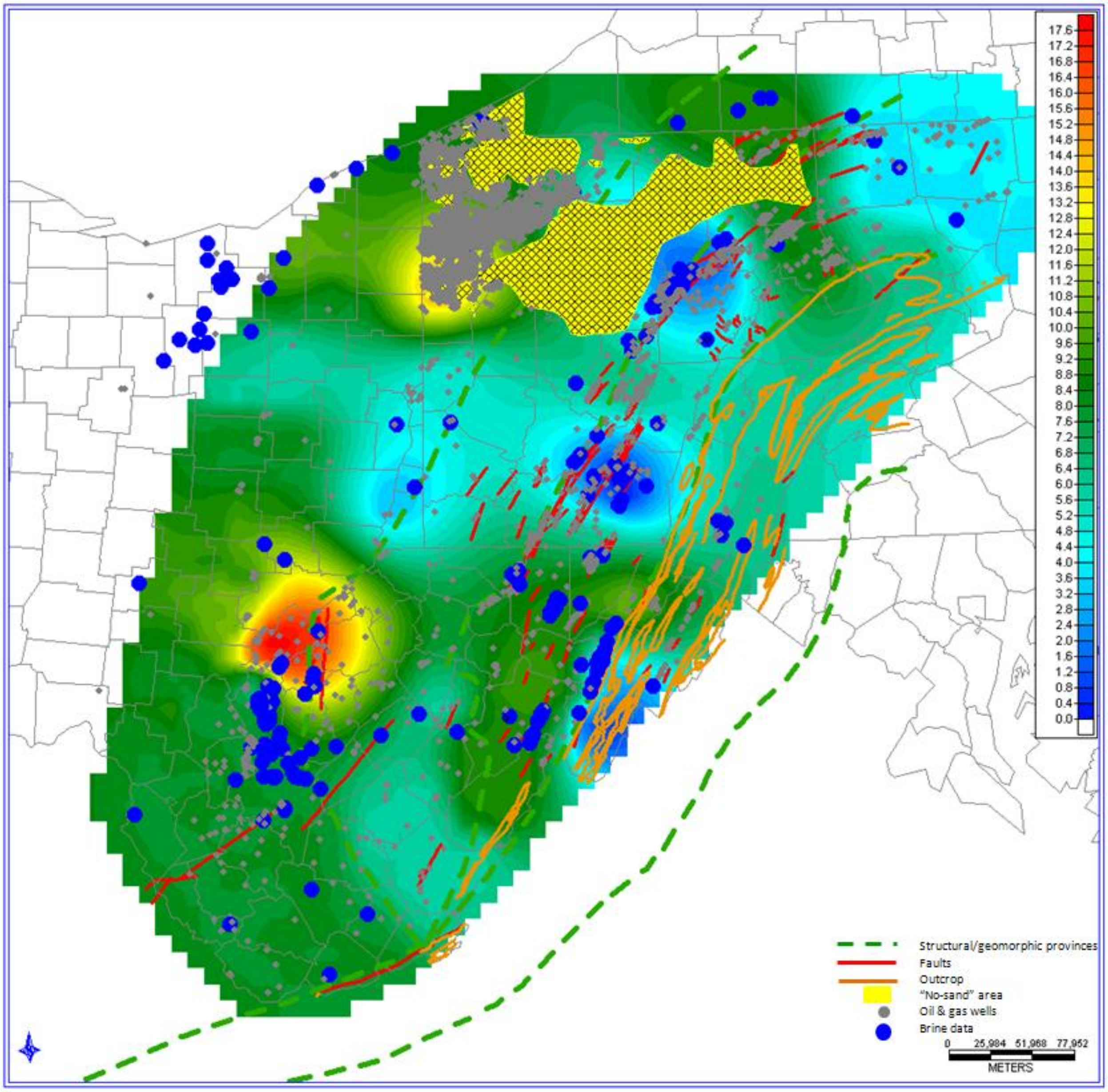

Figure 3-1. Oriskany Sandstone porosity map. Contour interval is 0.2 porosity units.

4 **FLOW VARIABLES AND CHEMISTRY OF FORMATION WATER**

4.1 METHODOLOGY

4.1.1 TEMPERATURE

Bottom-hole temperatures (BHTs) are recorded during logging of the borehole and commonly are not at equilibrium with formation temperature and require correction. Temperatures from shallow boreholes are generally too high, and temperatures from deep boreholes are too low (Appendix I). One method to correct for these erroneous BHTs is to plot the values versus depth, with the mean surface temperature (12° C for the Appalachian basin) providing an intercept (Forster et al., 1999). Figure 4-1 shows a plot of Oriskany bottom-hole temperature versus depth for 57 wells. By comparing the regression equation between the uncorrected and corrected intercepts a correction factor can be generated.

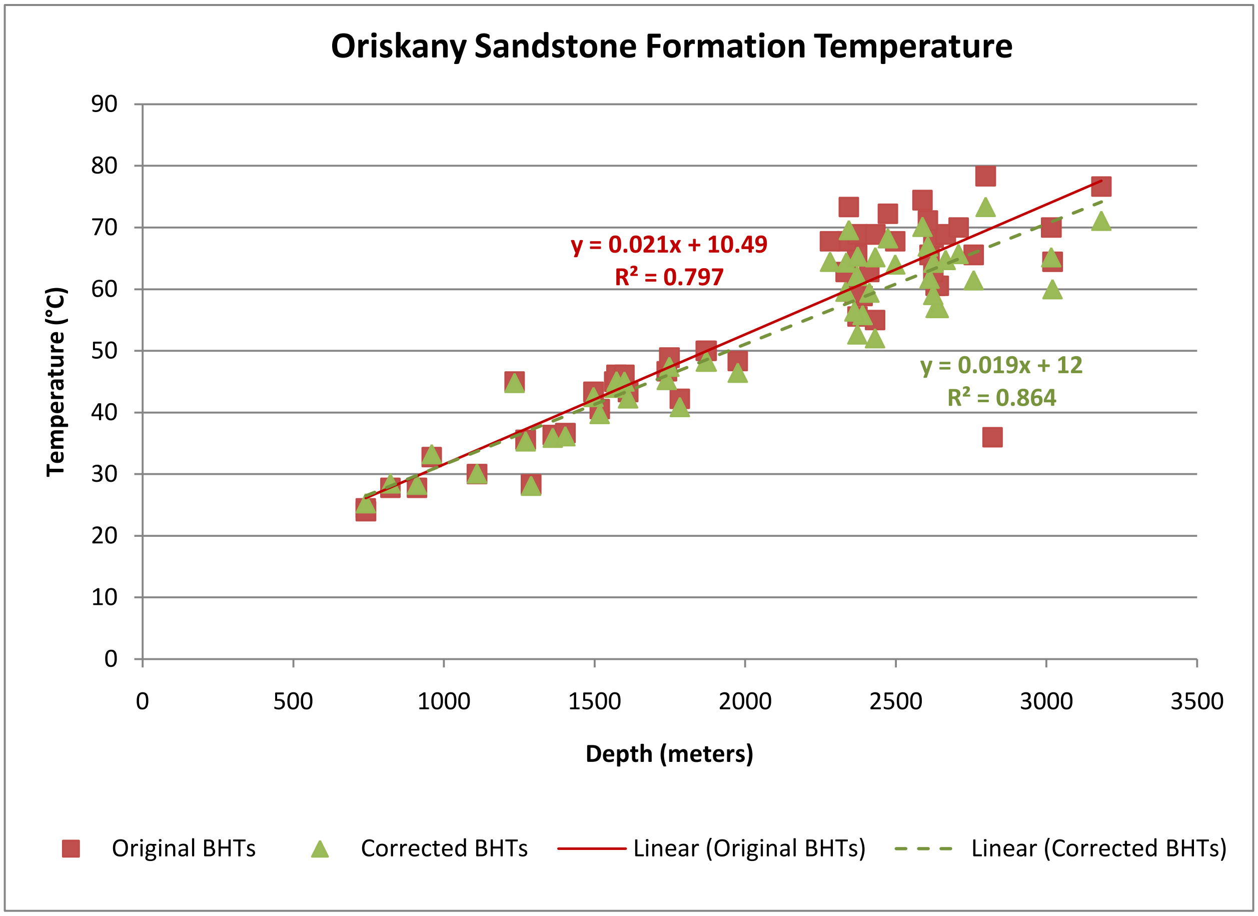

Figure 4-1. Oriskany Sandstone formation temperature (°C) plotted against depth (m). Data from 57 wells provided in Appendix I.

4.1.2 PRESSURE

Under hydrostatic conditions, pressure increases with depth at the rate of 9.74 kPa/m for freshwater and approximately 10.71 kPa/m for brine with 145,000 mg/L TDS. Recorded pressure, like temperature, is related to both depth and burial history (Carr et al., 2005). Measured pressure values may be influenced by drawdown from nearby wells, but these data were still retained because local production is thought to have little influence on regional-scale pressure features (Bachu and Undershultz, 1995). Final shut-in pressure versus depth for 225 wells in the Oriskany is shown in Figure 4-2 (Appendix II). The hydrostatic gradient for fresh water and brine are plotted over these data to test hypotheses that the Oriskany is either overpressured or underpressured (Figure 4-2).

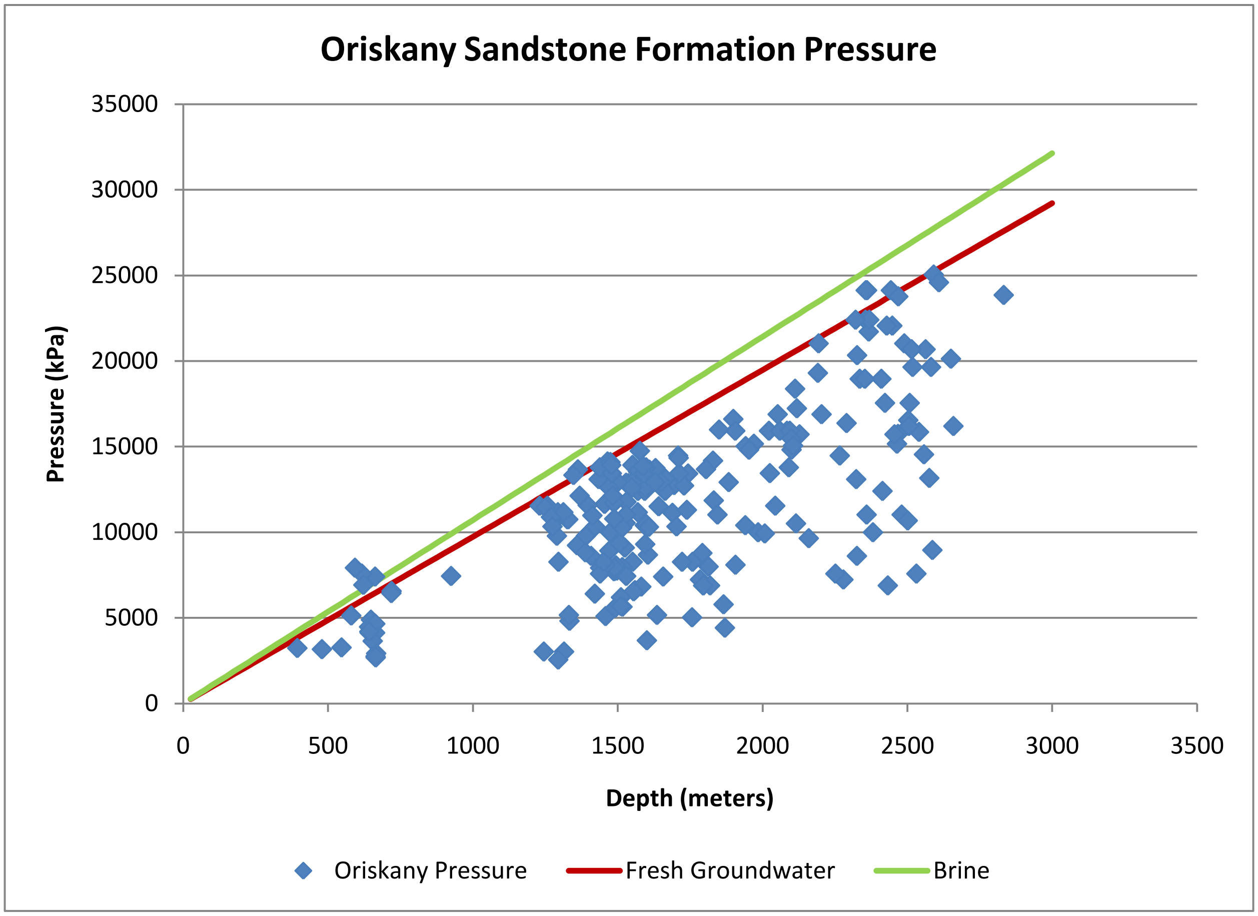

Figure 4-2. Oriskany Sandstone formation pressure (kPa) plotted against depth (m). Red squares indicate the idealized pressure gradient for fresh groundwater (TDS <10,000 mg/L). Green triangles indicate the idealized pressure gradient for brine (TDS=145,000 mg/L). Data from 225 wells provided in Appendix II.

4.1.3 TOTAL DISSOLVED SOLIDS (TDS)

Existing brine geochemical data was gathered from published and unpublished state and federal geological surveys, as well as local oil and gas companies. The data were checked for quality assurance based on the method described by Hitchon and Brulotte (1994) (Table 2). An additional ten brine samples were collected from existing oil and gas wells distributed throughout the Appalachian basin, with an attempt made to collect new sample sites in areas of data gaps (Appendix III). The location of these brine samples depended on the participation and cooperation of local oil and gas companies. The brine samples were collected according to United States Geological Survey (USGS) standards in 500 mL high-density polyethylene bottles that were labeled with well location, sampled formation, depth, and date (USGS, 2006).

The samples were shipped to and analyzed at the Geochemical Testing Laboratory located in Somerset Pennsylvania. Analytes included: Alkalinity, TDS, and concentrations of calcium (Ca), sodium (Na), magnesium (Mg), potassium (K), chloride (Cl), and sulfate (SO_4). Alkalinity ($CaCO_3$) concentration, which includes carbonate (CO_3) and bicarbonate (HCO_3), were determined by the titrimetric method according to the Association of Official Analytic Chemists (AOAC) standards with a detection limit of 2 ppm $CaCO_3$. Total dissolved solids (TDS) concentrations were measured using the American Society of Testing and Materials (ASTM) gravimetric method with a detection limit of 0.8 mg/L. The Environmental Protection Agency (EPA) Method 300.0 of ion chromatography was used to measure the Cl and SO_4 content with a detection limit of 0.03 ppm (O'Dell et al., 1993). The concentration of the cations Ca, Mg, K, and Na were calculated using inductively coupled plasma mass spectroscopy (ICP-MS) with detection limits of 50, 1.0, 30, and 5 µg/L, respectively.

4.1.4 GROSS FLUID FLOW

Darcy's law describes fluid flow in a porous medium. When it is written in terms of hydraulic head rather than pressure, it shows that the flow of formation water is driven by hydraulic gradients, density differences, and variations in temperature and chemical concentrations (Bachu, 1995b). For sedimentary basin-scale flow systems, temperature and chemical concentration differences are generally thought to be unimportant by comparison with hydraulic- (topographic) and buoyancy-driving mechanisms (Bachu, 1995a, 1995b). Buoyancy, due to density differences, can potentially play an important role by opposing and retarding the flow of formation waters driven by hydraulic-head gradients (Bachu, 1995b).

In order to analyze the flow pattern, the formation pressures were used to calculate equivalent freshwater hydraulic head, H_o:

$$H = (p/\rho_o g) + z \quad \text{(Formula 1)}$$

where p is formation pressure, $\rho_o = 1000\ kg/m^3$ (density of freshwater), g is the gravitational constant $9.80665\ m/s^2$, and z is elevation relative to sea level (Bachu and Undershultz, 1993, 1995; Anfort et al., 2001). Formation waters in sedimentary basins become less dense as temperature increases, but denser as salinity increases. Therefore, density variations have the potential in introduce error in freshwater hydraulic head estimates (Bachu and Undershultz, 1993, 1995). An indication of the magnitude of this introduced error is given by the dimensionless driving force ratio (DFR) defined (Davies, 1987; Bachu, 1995) as:

$$DFR = (\Delta\rho|\Delta E|) / (\rho|\Delta H_o|_h) \quad \text{(Formula 2)}$$

where $|\Delta E|$ is the magnitude of the aquifer slope, $|\Delta H_o|_h$ is the magnitude of the horizontal component of the freshwater hydraulic-head gradient, $\Delta\rho$ is the difference between formation-water and freshwater densities. If the DFR value is greater than 0.5, neglecting buoyancy effects will introduce significant errors in flow analysis using an equivalent head concept (Davies, 1987). However, according to Aufont, et al., (2001), the presence and direction of flow will be correct but the magnitude will be less than indicated. This is due to hydraulic gradients and buoyancy acting in opposite directions along dip. The values for H_o thus calculated were mapped with Petra using the minimum curvature parameters and the resulting gradients were used to estimate the flow direction and strength.

4.2 RESULTS

4.2.1 TEMPERATURE

Figure 4-1 shows correcting for erroneous BHTs in the Oriskany to a zero-depth intercept of 12 °C (average surface temperature) to yield a linear geothermal gradient by regression of:

$$T = 0.0195d + 12 \quad \text{(Formula 3)}$$

where T is in degrees Celsius and d is in meters. This is approximately 20°C/km, low for cratonic rocks, typically 25 to 30 °C/km. Hitchon (1984) attributes low geothermal gradients to topographically-controlled hydrodynamic flow. The newly calculated geothermal gradient values were used to generate a map with Petra of subsurface temperature of the Oriskany using the minimum curvature method (Figure 4-3). The resulting grid will be used in estimating the solubility trapping capacity of the Oriskany.

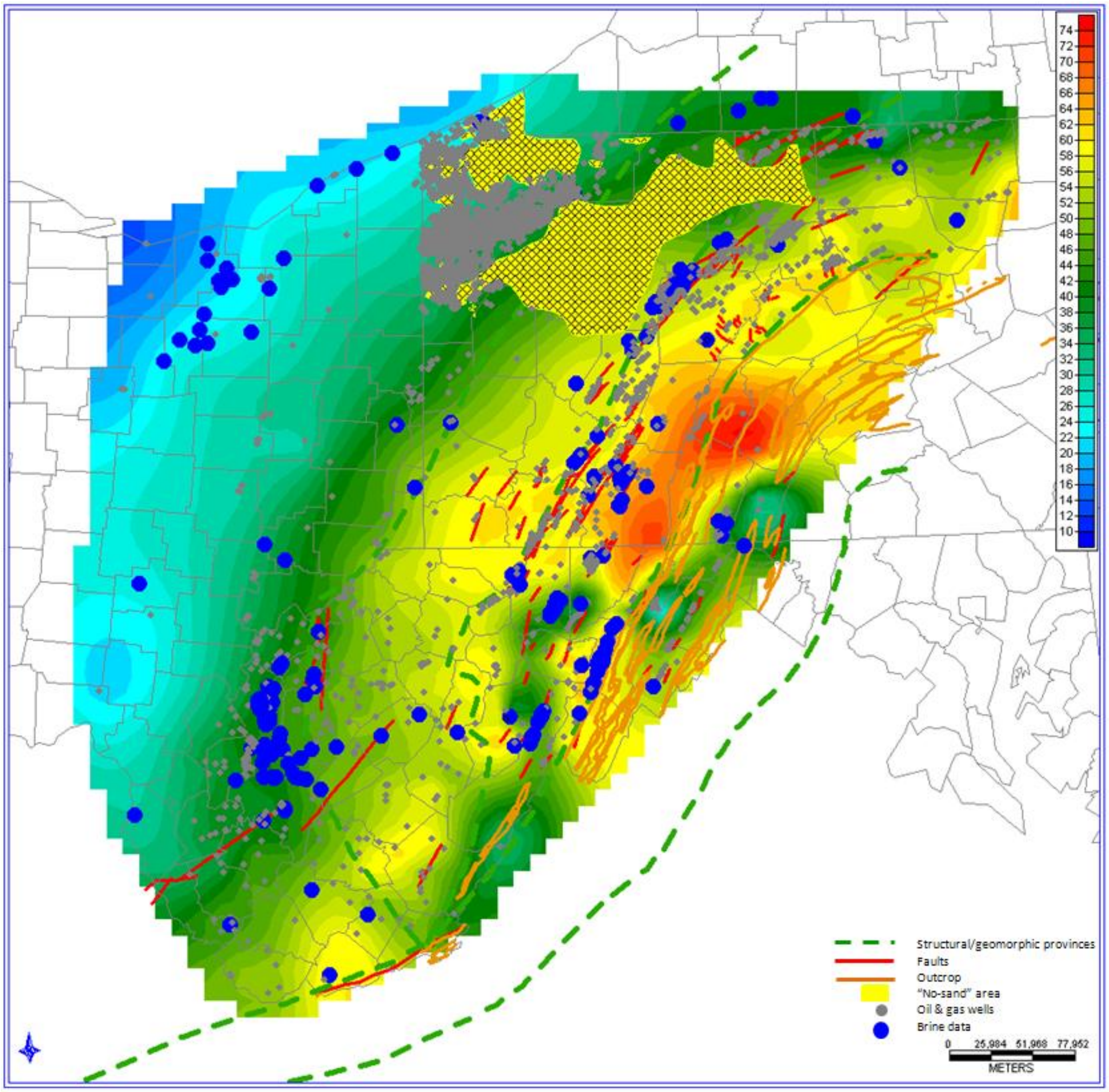

Figure 4-3. Oriskany Sandstone formation temperature (°C) using the newly calculated gradient. Contour interval is 2° C.

4.2.2 PRESSURE

Final shut-in pressure recorded from gas wells of the Oriskany (based on n = 225 wells) is significantly below the expected hydrostatic gradient for fresh groundwater. Pressure plotted against depth indicates that the Oriskany is underpressured (Figure 4-4). This underpressure below hydrostatic for either fresh or average-salinity water (lines on Figure 4-2) may be due to drawdown from nearby wells and/or lack of sufficient shut-in time to reach pressure equilibrium. However, a few cases (< 5%) of overpressure were observed but the Oriskany reservoirs at a regional scale appear to be underpressured. Abnormally low reservoir pressures can be caused by gaseous diffusion and gas shrinkage in reservoirs that have been uplifted or otherwise cooled (Russell, 1972; Belitz and Bredehoeft, 1988; Bachu and Undershultz, 1995). The High Plateau of the central Appalachian basin is the area with the highest pressure values.

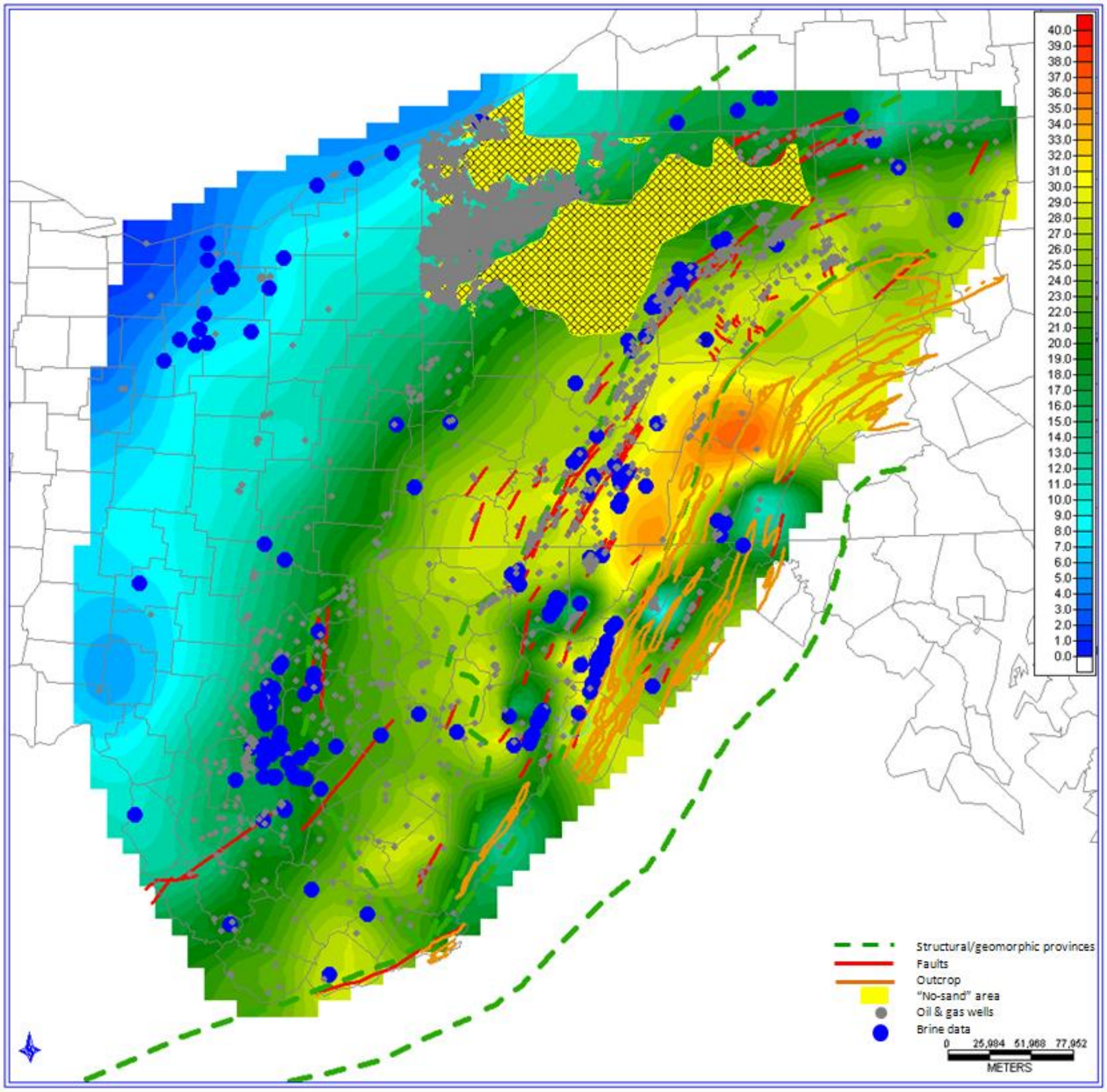

Figure 4-4. Oriskany Sandstone formation pressure (kPa) at top of structure using the newly calculated pressure gradient. Contour interval is 1 kPa.

4.2.3 TOTAL DISSOLVED SOLIDS (TDS)

Oriskany brine geochemical data were compiled from published and unpublished sources (Stout, et al., 1932; Price, et al., 1937; Hoskins, 1947; Poth, 1962; Kelley, et al., 1973; Woll, 1978; Dresel, 1985; Lloyd and Reid, 1990; Chesapeake Energy; and NatCarb). Additional brine samples were collected from ten existing oil and gas wells and storage fields distributed throughout the Appalachian basin. Across the extent study area, the TDS ranges from fresh (TDS < 10,000 mg/L) to brine (TDS > 300,000 mg/L) (Figure 4-5). The brines are concentrated in the structural lows at the center of the basin, while the relatively low TDS concentrations are associated with the outcrop areas to the east and the west.

Recharge of meteoric waters into saline brines can dilute salinity and enhance methanogensis (Martini et al., 1998; McIntosh et al., 2002). Thermogenic gas, on the other hand, is generated by the thermal degradation of organic material at depth and is typically associated with saline brines (McIntosh and Martini, 2005). Formation waters associated with microbial gas generally have low Ca/Mg ratios (<1.5) as a result of calcite precipitation induced by microbial methanogenesis (Martin et al., 1998). Low Ca/Mg ratios can also be used to infer freshwater incursion. The ratio of calcium concentration to magnesium concentration for the Oriskany across the Appalachian basin is generally less than ten, and even lower (<5) in the recharge and outcrop areas to the east and west (Figure 4-6). The ratio is as high as 30 in the northeast area of the basin.

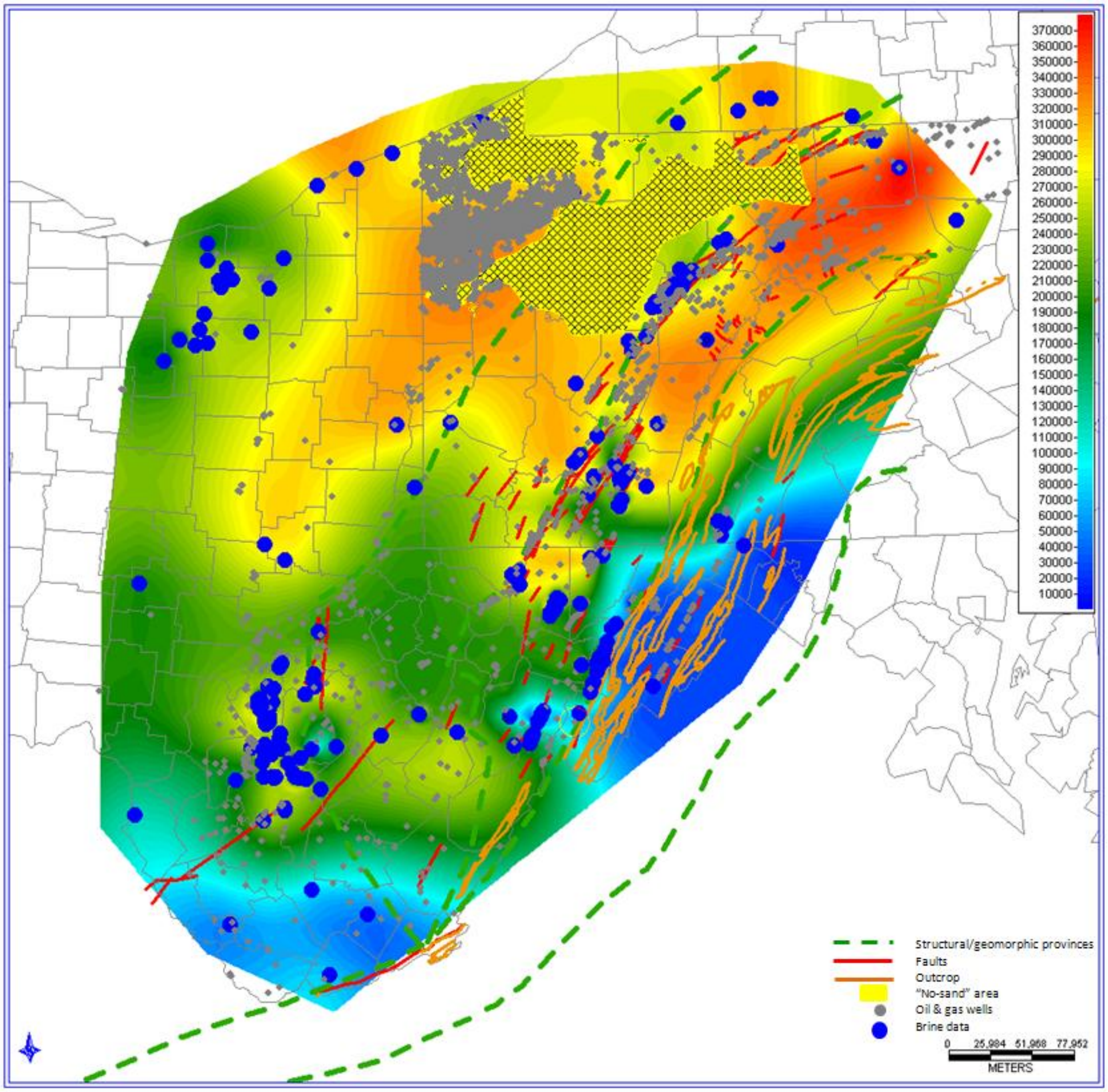

Figure 4-5. Oriskany Sandstone TDS (mg/L) map. Contour interval is 5,000 mg/L.

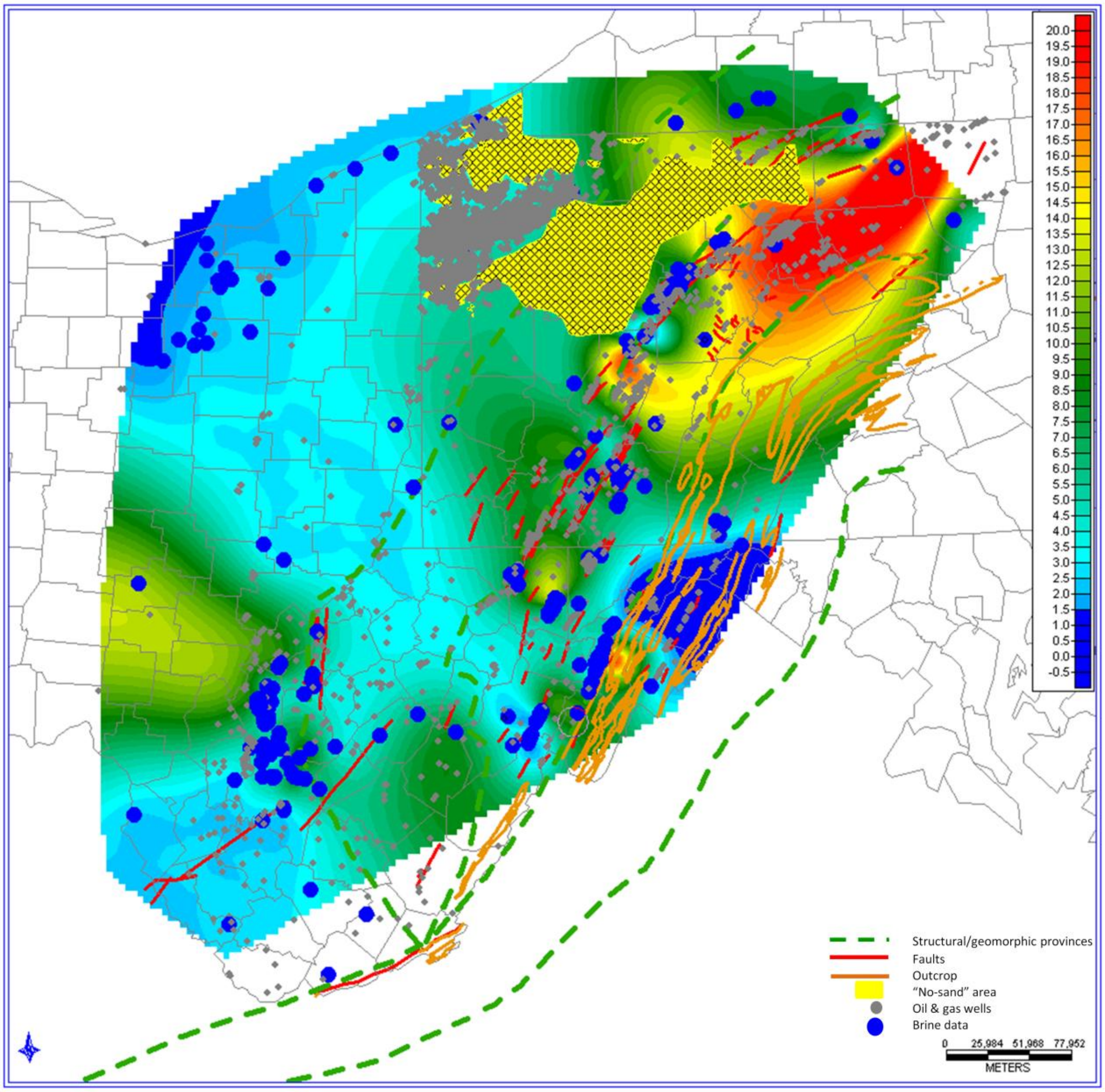

Figure 4-6. Oriskany Sandstone Ca/Mg concentration ratio map. Contour interval is 0.5. Values < 1.5 indicate possible freshwater incursion.

4.2.4 GROSS FLUID FLOW

Formation pressure was used to calculate equivalent freshwater hydraulic head H_o (Formula 1). Use of freshwater hydraulic heads in the flow analysis of variable-density formation waters may introduce significant errors, depending on the interaction between the potential and buoyancy forces driving the flow (Bachu and Undershultz, 1993, 1995). Density values were calculated from salinity, temperature, and pressure using the relationships published by Gill (1982)(Appendix IV; Figure 4-7). Across the extent of the Oriskany the density ranges from approximately fresh water (1,030 kg/m^3) to a density of 1,300 kg/m^3. The formation water with the highest density is concentrated in the Oriskany structural lows at the center of the basin. The formation water with the lowest density is associated with the outcrop area to the east and the subcrop or pinch-out area to the west.

An indication of the significance of this introduced error is given by the dimensionless driving force ratio (DFR) (Formula 2). If the DFR value is greater than 0.5, neglecting buoyancy effects will introduce significant errors in flow analysis (Davies, 1987). Within the Oriskany the values were generally much less than 0.5, with the exception of two areas located in south-central Pennsylvania. Hydraulic heads (Figure 4-8) range from over 1,000 m in the deeper part of the basin to less than 250 m at the potential recharge area to east and the potential discharge area to the west.

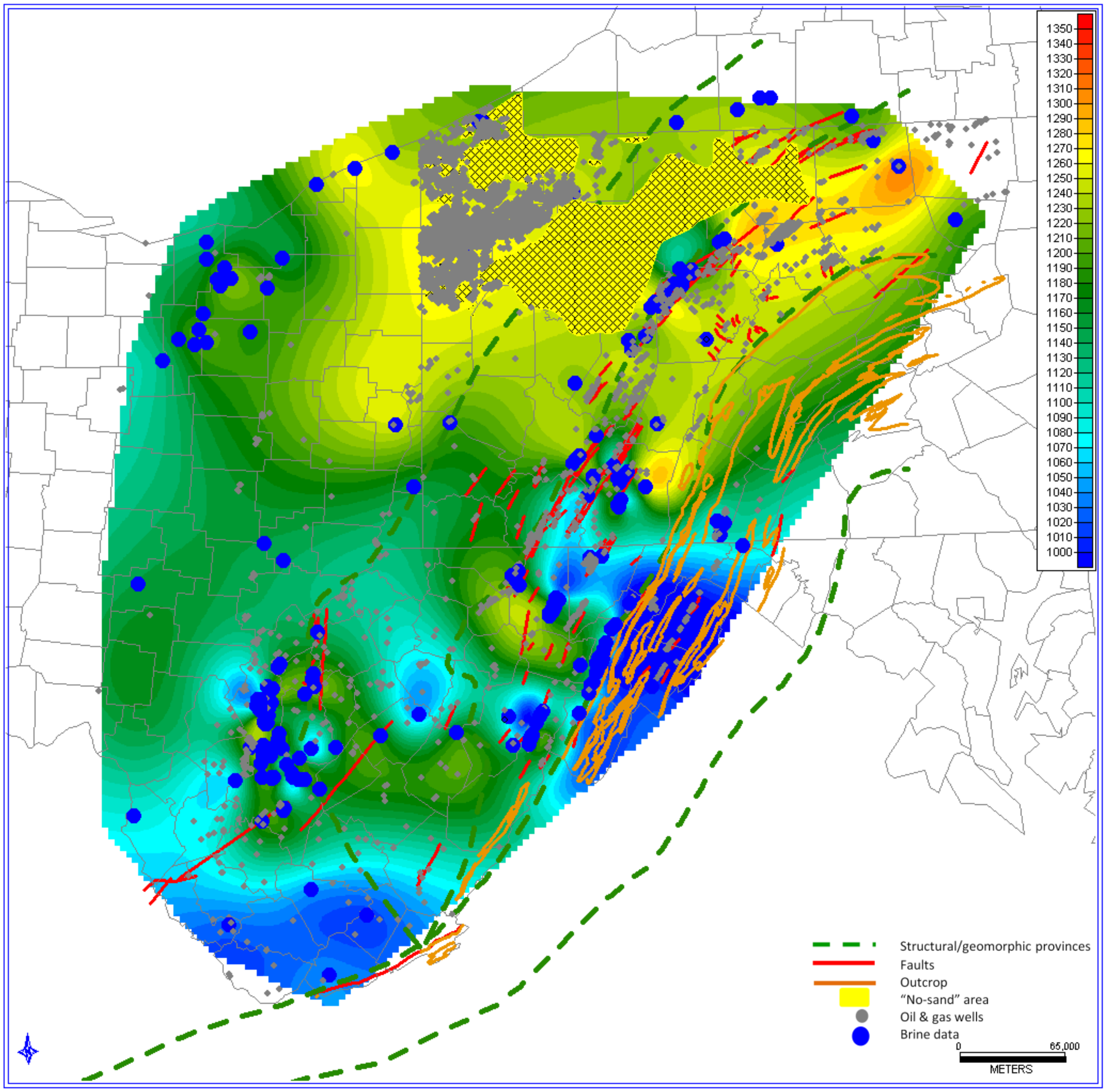

Figure 4-7. Oriskany Sandstone formation water density map. Contour interval is 10 kg/m^3.

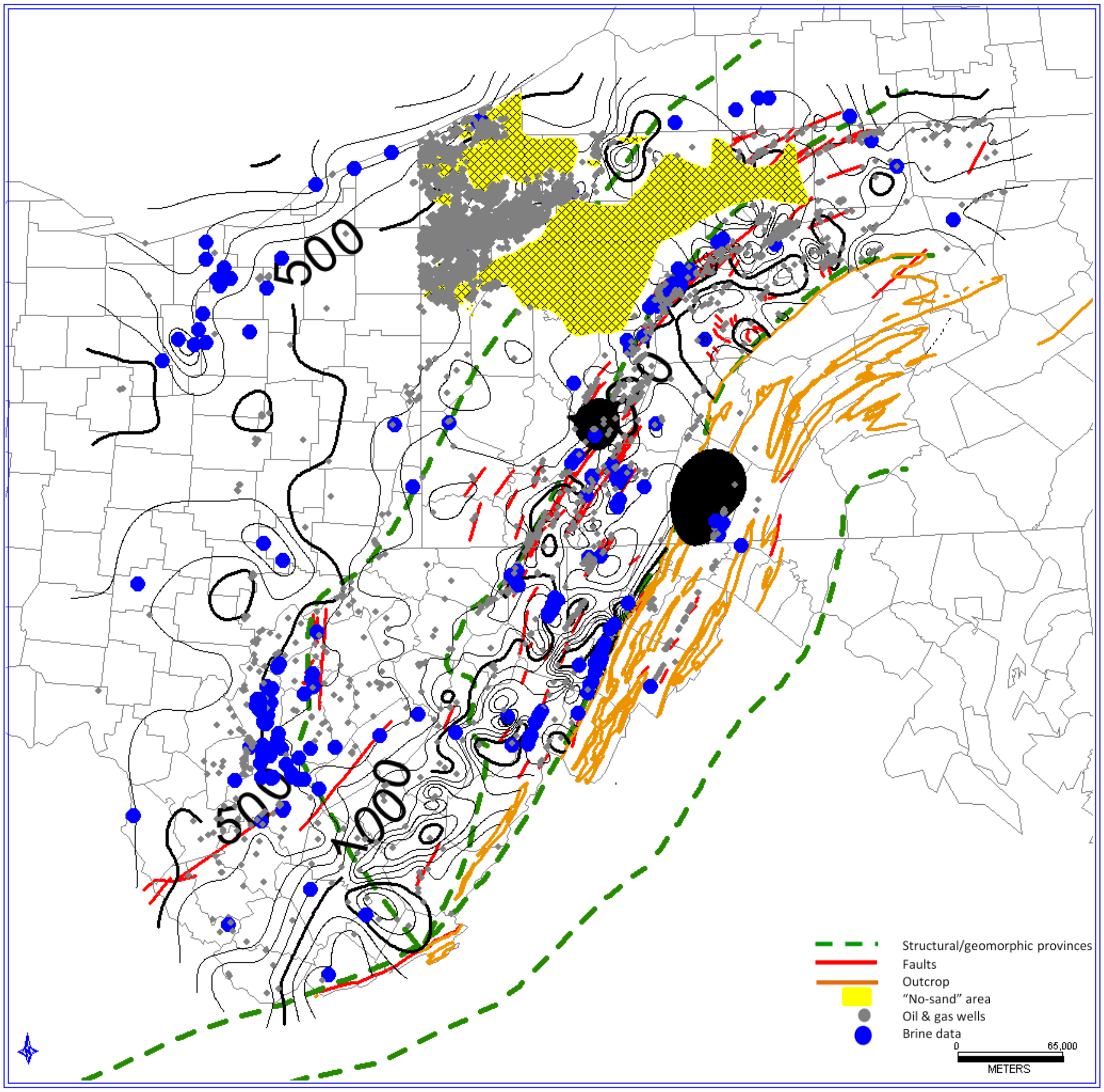

Figure 4-8. Oriskany Sandstone equivalent hydraulic head contours with areas indicated in black in which DFR values exceed 0.5. Contour interval is 500 meters.

5 ANALYSIS OF RESULTS

5.1 BASIN FRAMEWORK

The Oriskany dips toward the center of the basin, a trend that is consistent with the preserved northeast-southwest central axis. The Oriskany shallows toward the outcrop area to the east along the Allegheny Front and Eastern Overthrust Belt and toward the Cincinnati Arch toward the west. The Oriskany is typically thickest, over 75 meters, in the Eastern Overthrust Belt and the High Plateau and thins, to a thickness less than 10 meters, toward the northwest, west, and south. Using the depth and isopach data the volume estimate of approximately 2,188 km^3 will be used to calculate a total Oriskany CO_2 storage capacity

5.2 ROCK PROPERTIES

The average 8.08% porosity value calculated for this study is consistent with the value calculated by Dilmore and others (2008) for the USDOE. This value indicates that the Oriskany has the potential to provide adequate porosity for the injection of supercritical CO_2 (Bachu, et al., 2007). The areas of the Appalachian basin that had the lowest estimated porosity values were the areas of greatest depth (>2,000 m MSL).

5.3 FLOW VARIABLES AND CHEMISTRY OF FORMATION WATER

The temperature data was corrected for erroneous BHTs that are often encountered during drilling, and are therefore directly related to depth. There was no indication that any temperature anomalies existed in the Oriskany before processing. The geothermal gradient for the Oriskany Sandstone (~20°C) is lower than that expected for cratonic rocks (25-30°C) (Hitchon, 1984). The pressure values indicate that the Oriskany is underpressured. This underpressuring is an indication of the integrity and longevity of the overlying confining layer which will serve as a vertical seal for sequestered CO_2 (Puckette and Al-Shaieb, 2003). There is some indication that drawdown from nearby wells and insufficient shut-in time may have an effect on some wells within the Oriskany study area. The High Plateau of the central Appalachian basin is the area with the highest pressure values, which is consistent with the suggestion of Russell (1972) that correlates high pressure values not only with depth but also deformation.

The TDS concentrations of the Oriskany formation fluids range from freshwater to dense brine. The brine samples were characterized by large differences between the reported TDS concentrations from neighboring wells within the same gas field. The cause of these differences may be related to areal, vertical, and temporal variability, errors introduced from sampling procedures, or to varying methods of chemical analysis (Jorgensen, et al., 1993). The dense brines were concentrated in the Oriskany structural lows in the center of the basin and to the north. The relatively lower TDS concentrations are at the outcrop area to the east and the subcrop area to the west. This trend would seem to indicate that any mixing of formation water with meteoric water occurs only along the outcrop and subcrop margins or along fault traces. The low Ca/Mg ratios along the outcrop and subcrop margins can also be used to infer freshwater incursion (Martin et al., 1998). The distribution of freshwater hydraulic head shows the expected trends of northwestward and southeastward flow from the basin center toward the western subcrop area and the eastern outcrop area and further substantiates the previous assumption.

6 INTERPRETATION

The Oriskany Sandstone of the Appalachian basin is a widely distributed saline aquifer which has produced large quantities of hydrocarbons and is used extensively for storage of natural gas. Oriskany gas storage fields have the capability to store/deliver more natural gas than storage fields in any other formations within the northern Appalachian basin (American Gas Association, 2001). At least 32 gas storage fields are found within the Oriskany, with a combined storage capacity approaching 1 trillion cubic feet (TCF). Many of these storage fields have been in operation since the 1950's attesting to the ability of these fields and seals to maintain long-term containment (AGA, 2001). This indicates that at the local level the Oriskany has the necessary volume, porosity, and containment characteristics for geologic storage of CO_2 (Cook and Benson, 2005; Czernichowski-Lauriol et al., 2006; Bachu et al., 2007; Dilmore et al., 2008).

Using published and unpublished data of rock characteristics, pressure, temperature, and formation water geochemistry along with new brine samples were used to map the regional-scale hydrogeological regime and its relation to the migration of hydrocarbons and geologic CO_2 sequestration potential. Basin-scale fluid flow of the Oriskany formation waters is generally controlled by salinity differences and by differences in structural elevation. The flow pattern is substantiated by the salinity distributions and water geochemistry, with relatively lower salinity at recharge to the east and discharge to the west due to mixing with fresh meteoric water and higher salinity between the recharge and discharge zones. The basin-scale flow pattern is also substantiated by the distribution of oil and gas fields that occur in the central Appalachian basin; the major productive gas fields occur at the boundary between lower salinity and are typically absent in areas of higher salinity. It is believed that hydrocarbon distribution is influenced by basinal variations in buoyancy and entrainment by the formation water flow (Hitchon, 1984).

Long-term lateral containment of large-scale CO_2 injection appears to be associated in the Oriskany with convergent flow located in the eastern Appalachian basin. Storage capacity for the Oriskany saline formation is estimated by the equation:

$$G_{co2} = A h_g \phi_{tot} \rho E \qquad \text{(Formula 4)}$$

G_{CO2} is the estimate of total saline formation storage capacity in kilograms, A is the area of basin greater than 800 meters in depth, h_g is the average thickness of formation at depths greater than 800 meters, ϕ_{tot} is the average formation-scale porosity for thickness h_g (8.08%), ρ is the density of CO_2 at pressure and temperature that represents storage conditions for saline formation averaged over h_g (800 kg/m^3 at P = 18.01 MPa and T = 43.29 °C), and E is the storage efficiency factor that reflects a fraction of total pore volume filled by CO_2 (USDOE estimations of E are a low of 0.01 and a high of 0.04).

Oriskany isopach and porosity grids were generated using Petra's minimum curvature method and a 10,000 by 10,000 meter grid size. These grids were then used to perform a grid-to-grid calculation to estimate the available volume within the potential CO_2 sequestration area (Figure 6-1). Grid-to-grid calculations were then performed using the constants for density of supercritical CO_2 (800 kg/m^3) and the storage efficiency factors (0.01 and 0.04) (Figures 6-2 and 6-3). The result is a storage resource estimate of 1.246 to 4.983 gigatonnes of CO_2.

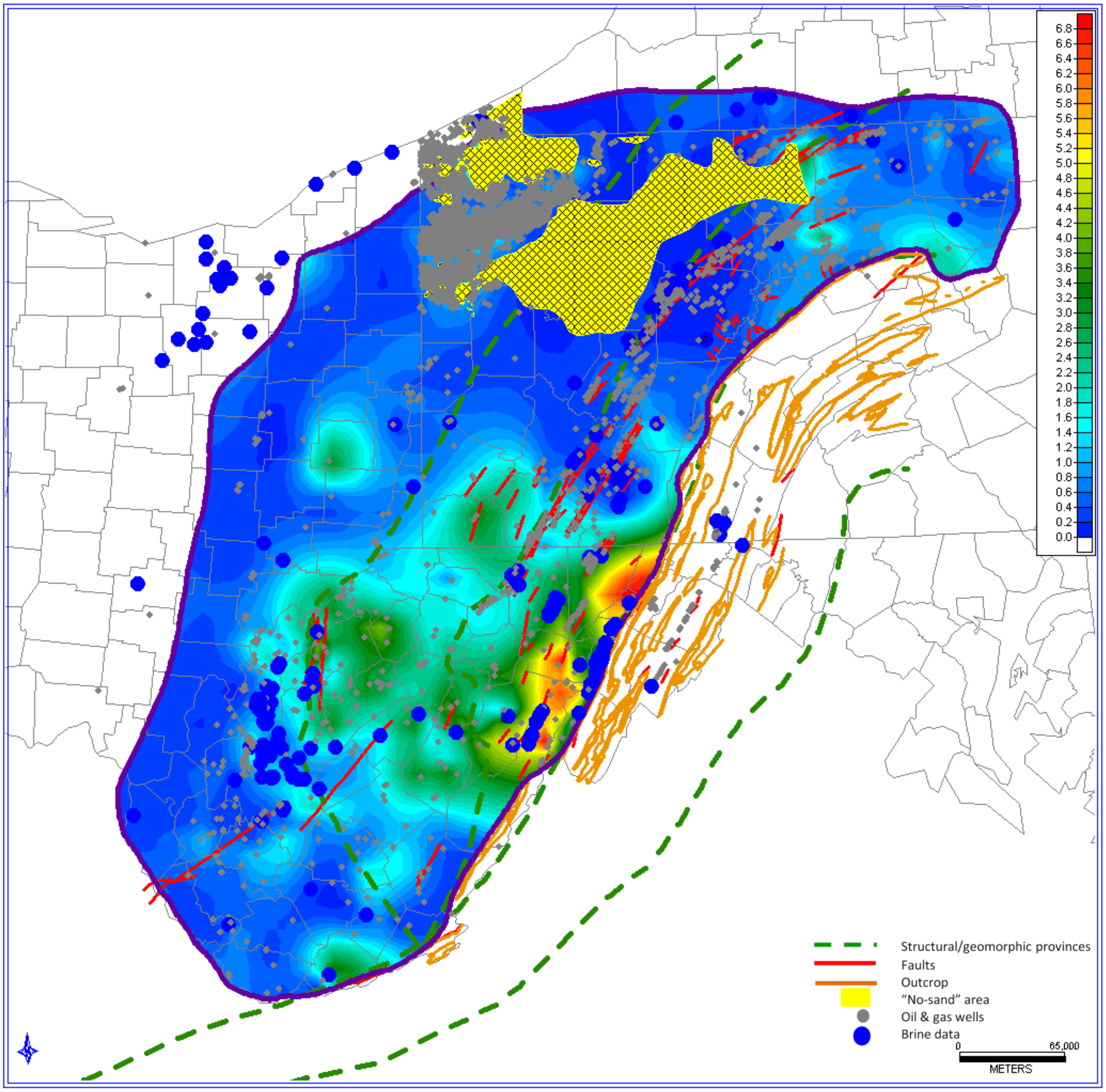

Figure 6-1. Oriskany Sandstone estimated pore volume map. Contour interval is 0.2 km^3 per 100 km^3.

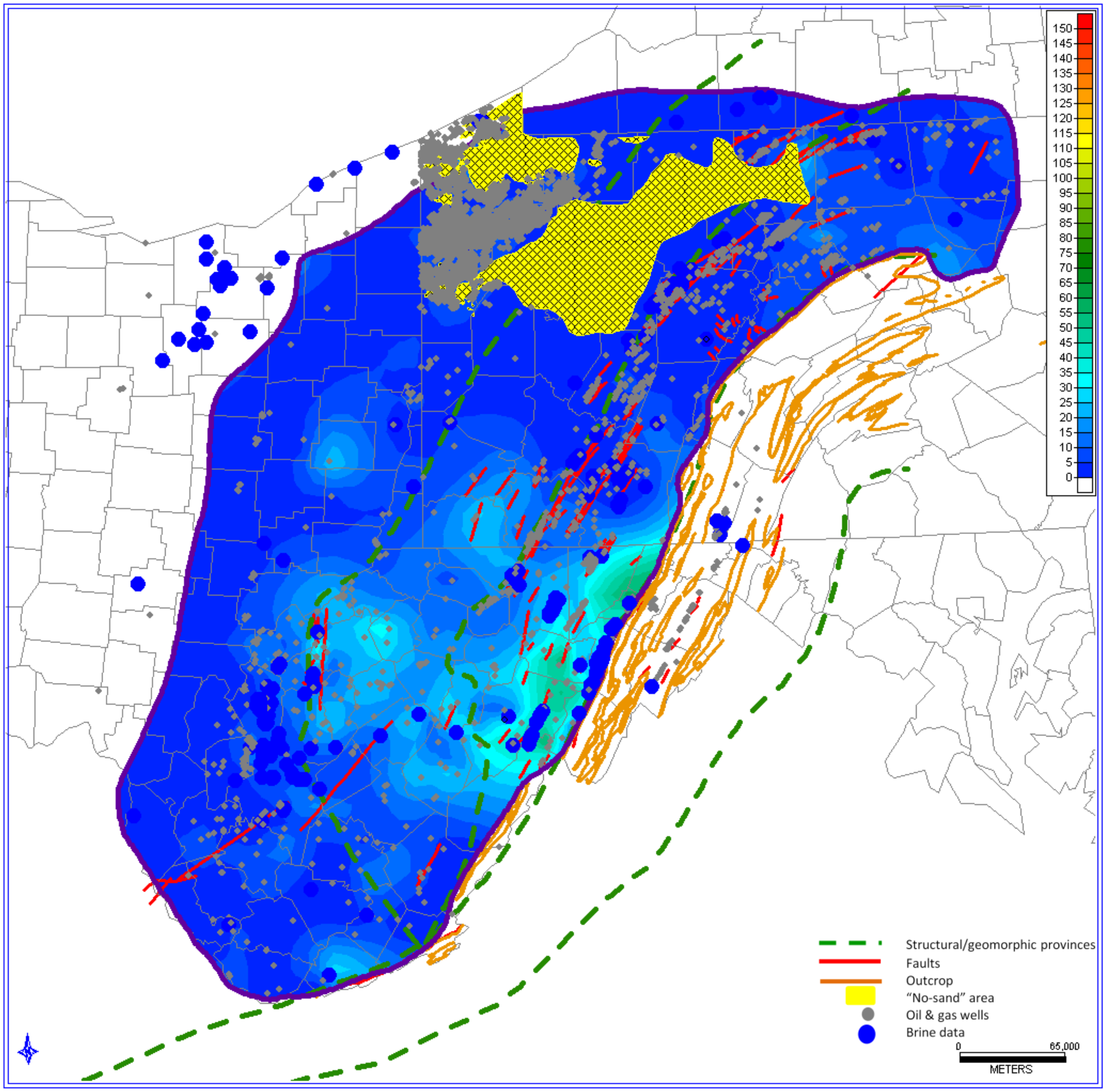

Figure 6-2. Oriskany Sandstone total storage capacity estimate using the low storage efficiency factor 0.01. Contour interval is 5 kg/m^3.

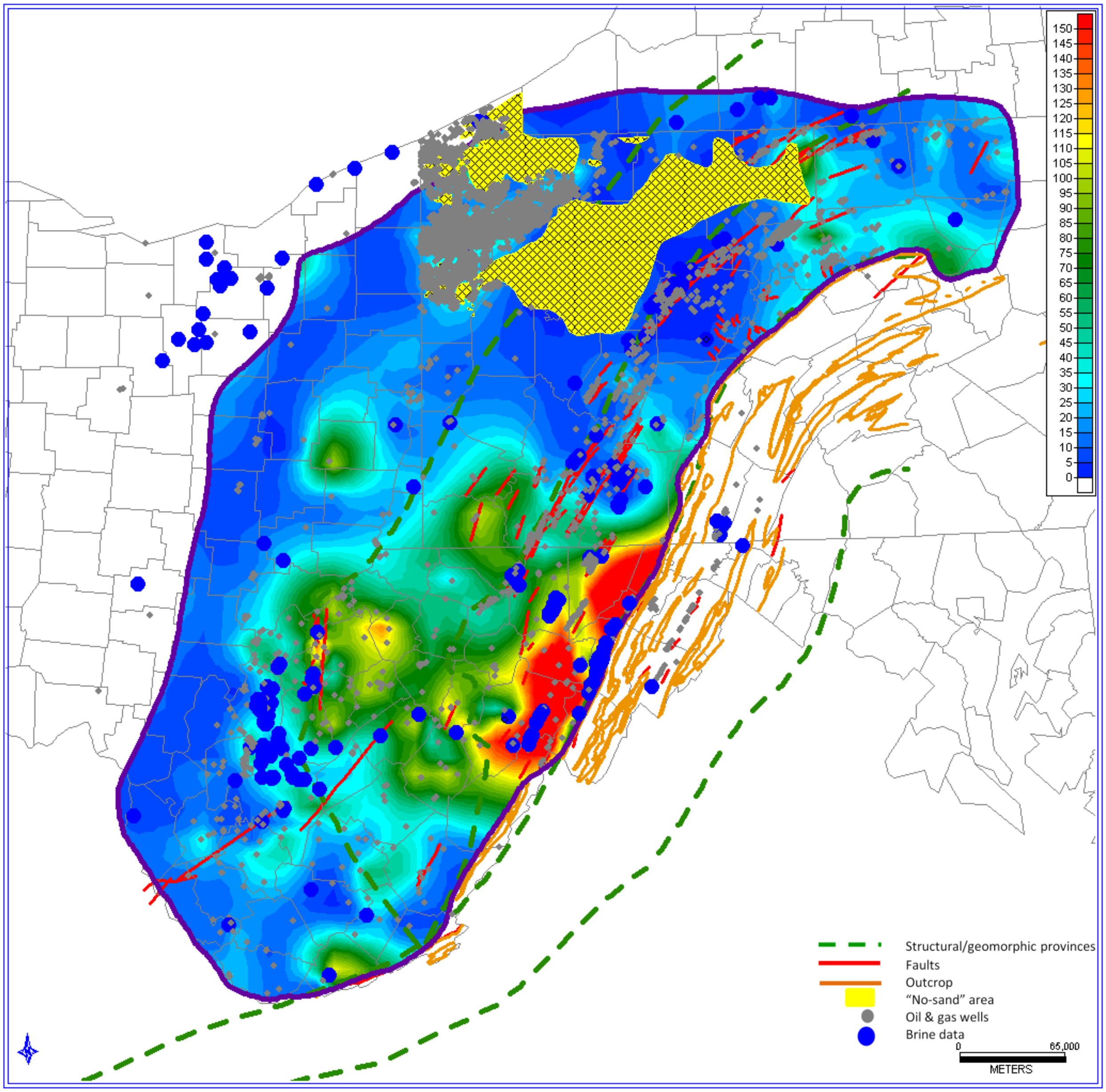

Figure 6-3. Oriskany Sandstone total storage capacity estimate using the high storage efficiency factor of 0.04. Contour interval is 5 kg/m^3

Using the method described by Dilmore et al. (2008) the solubility trapping capacity of the Oriskany saline formation can be estimated by the following equation:

$$CO_2 = \upsilon E \phi \delta m CO_2 M \quad \text{(Formula 5)}$$

CO_2 is the estimate of total mass of CO_2 in grams that can be trapped, υ is the total volume of the formation in km^3, E is the storage efficiency factor, ϕ is the estimated mean porosity, δ is the density of CO_2 saturated brine in kg/km^3, mCO_2 is the concentration of CO_2 dissolved in the brine in mol/kg, and M is the molar mass of CO_2 in g/mol (44.01g/mol).

The previous grid-to grid calculation for estimated pore volume within the potential CO_2 sequestration area was used with a value of 155.75 km^3. A grid was generated for the density of CO_2 saturated brine (δ) using the polynomial fit (Table 3) determined by Dilmore et al. (2008) to correlate temperature, pressure, and brine chemistry. A concentration of CO_2 dissolved in brine grid was also generated using the polynomial fit (Table 4) to correlate temperature to the formation CO_2 concentration using the parameters described above. Grid-to-grid calculations were performed to estimate the potential dissolved CO_2 storage capacity at the low and high storage efficiency factors (0.01 and 0.04) (Figures 6-4 and 6-5). The result is a solubility storage capacity estimate of 0.04 to 0.17 gigatonnes of CO_2.

At a regional scale, the Oriskany Sandstone appears to have the characteristics to be considered a geologic storage resource for storage of CO_2 supercritical fluids (Cook and Benson, 2005; Czernichowski-Lauriol et al., 2006; Bachu et al., 2007; Dilmore et al., 2008). However, site selection will require thorough evaluation of the formation. Such target sites include zones of high porosity and high permeability in areas of convergent hydrogeologic flow due to differences in salinity.

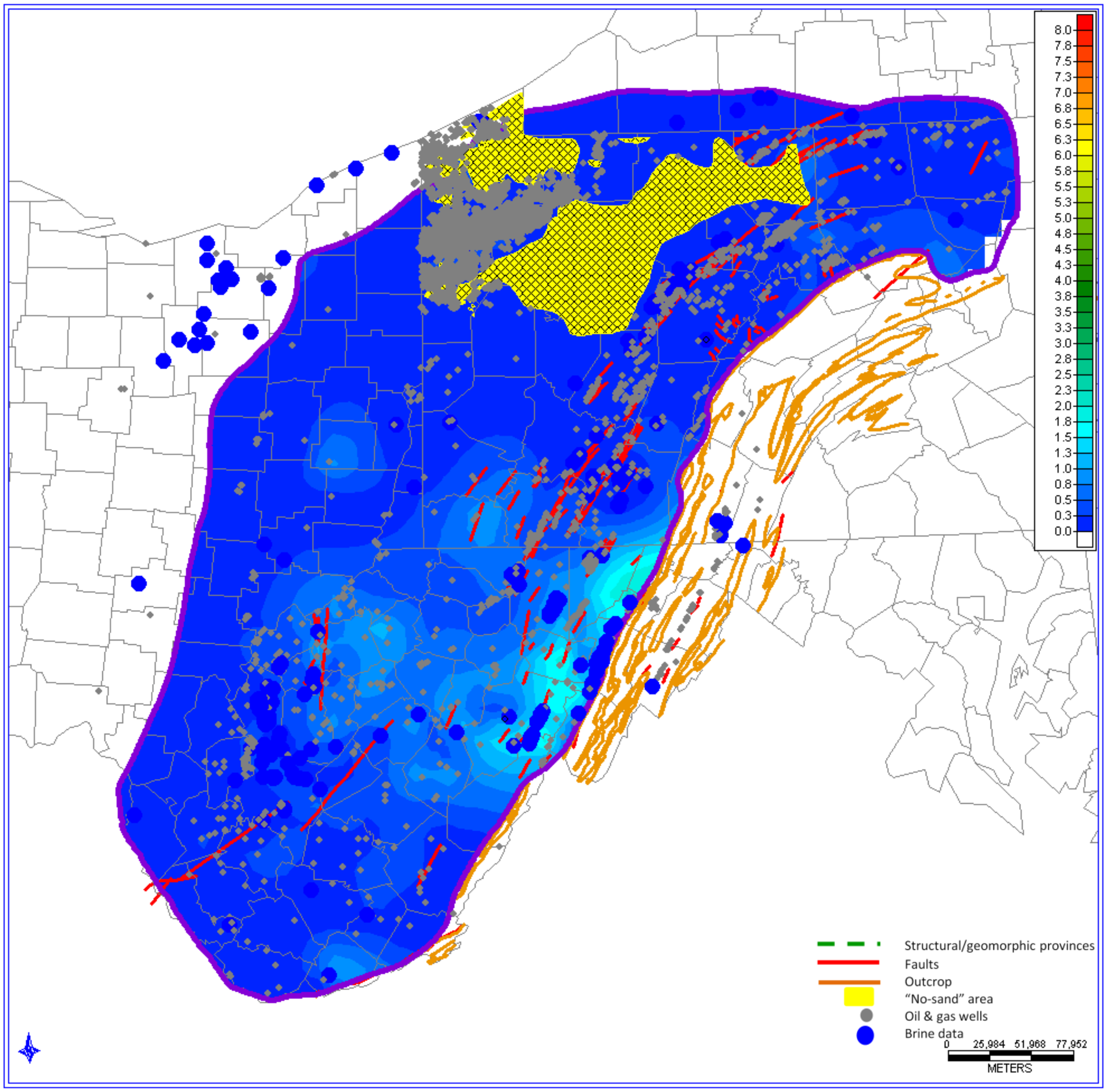

Figure 6-4. Oriskany Sandstone solubility storage capacity estimate using the Dilmore et al., (2008) method and the low storage efficiency factor of 0.01. Contour interval is 0.25 kg/m^3.

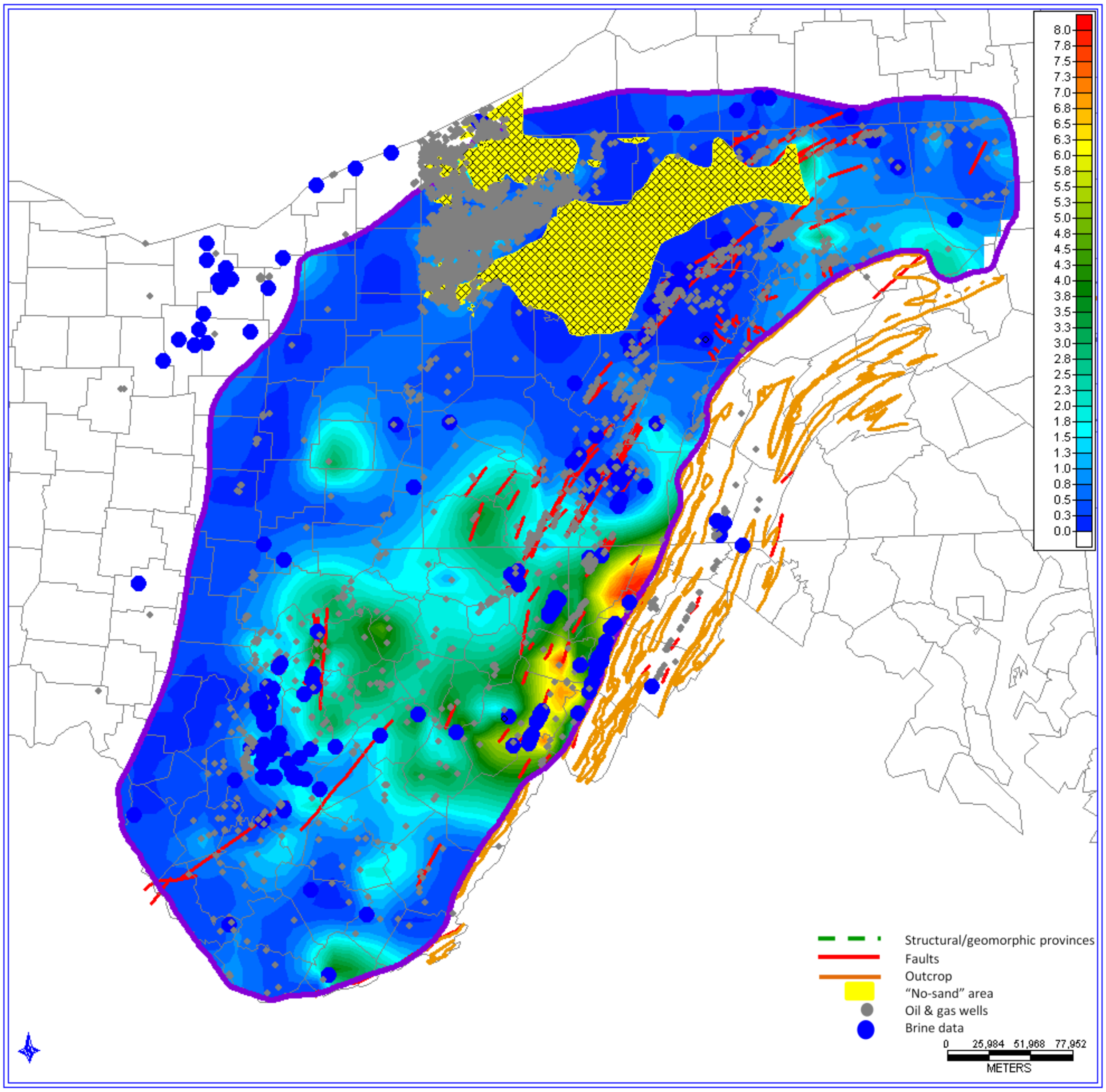

Figure 6-5. Oriskany Sandstone solubility storage capacity estimate using the Dilmore et al., (2008) method and the high storage efficiency factor of 0.04. Contour interval is 0.25 kg/m^3.

7 CONCLUSIONS

1. The geothermal gradient for the Appalachian basin, approximately 20°C/km, is lower than what is expected for cratonic rocks away from tectonic plate boundaries, 25-30°C/km, and would be considered a *cold* basin. In terms of CO_2 sequestration, *cold* basins are better than *warm* basins because the depth that CO_2 reaches supercritical conditions is shallower and therefore the CO_2 is less buoyant which lowers the potential for and the relative speed of CO_2 migration (Bachu, 2002). Hitchon, 1984, attributes low geothermal gradients to hydrodynamic flow.

2. The Oriskany of the Appalachian basin is generally underpressured with a pressure gradient of 6.8 kPa/m compared to a hydrostatic gradient of 9.74 kPa/m for freshwater and approximately 10.71 kPa/m for brine. This underpressuring would aid in sequestering CO_2 by lowering injection and displacement pressures and is an indication of the integrity and longevity of the overlying confining layers and weak lateral migration, which will serve as a vertical seal. These seals have prevented the Oriskany from equalizing with the hydrostatic environment and could help prevent the vertical and lateral migration of CO_2 (Puckette and Al-Shaieb, 2003).

3. The salinity of the Oriskany fluids varies widely across the Appalachian basin. The TDS ranges from freshwater (TDS < 10,000 mg/L) to dense brine (TDS > 300,000 mg/L). The relatively lower TDS concentrations are associated with the outcrop area to the east and indicate dilution by and mixing with fresh meteoric water. A high TDS concentration will decrease the solubility of CO_2. Variations in brine geochemistry and physical parameters strongly affect residual, solubility, and mineral trapping. Injected

CO_2 is soluble in brine and forms carbonic acid, which dissociates into bicarbonate and carbonate ions thereby lowering the pH. The Oriskany brine contains cations such as calcium, magnesium, and to a lesser extent iron, that can interact with the carbonate ions to form minerals such as calcite, dolomite, siderite and magnesite. The precipitation of these minerals occurs more favorably in a more basic pH (Soong et al., 2004). Reactions of CO_2 charged saline fluids with minerals likely found in sandstone such as the Oriskany results in an increase in pH and therefore a greater capacity for the fluid to sequester dissolved CO_2 (Allen et al., 2005).

4. Divergent flow patterns, based on hydraulic head estimates, are associated with the outcrop belt to the east and the area from the "no-sand area" southeast through the northern panhandle of West Virginia. These areas indicated also correspond to areas that historically have had low or no oil and gas production. Convergent flow patterns, based on hydraulic head estimates, are located within the High Plateau region, extending from New York toward the Allegheny Front. This area is associated with hydrocarbon production and has the potential for improved containment of injected CO_2.

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9 Tables

Table 1. Oriskany Sandstone porosity data.

State	County/Area	Field Name	Average Core Porosity (%)
New York	Southwestern Counties	N/A	9.0
Pennsylvania	Beaver		5.2
	Bedford		4.0 – 8.0
	Clinton	Leidy	8.09 – 8.58
	Elk		1.7
	Erie	Erie	8.6
	Potter	Leidy	8.3
	Somerset	Winding/Boardman	6.0 – 7.0
	Somerset	Engleka/Hemminger	0.14 – 0.20
	Somerset	West Ashtola	0.32 – 0.35
	Somerset	North Jerome	0.87 – 1.04
	Somerset	Coxes Creek	0.72
	Somerset	Lavansville	0.29 – 0.78
	Greene	Shamrock	1.17
	Indiana	Buffington/Pine	6.2
	Lawrence	Mt. Jackson	8.0 – 21.0
West Virginia	Tucker	Canaan Valley	7.0
	Kanawha	Elk-Poca	8
	Jackson	Elk-Poca	8
	Jackson	Rockport	17
	Putnam	Elk-Poca	8
	Randolph	Randolph/Tucker	9
	Tucker	Randolph/Tucker	9
	Wood	Rockport	17

Table 2. Criteria for culling formation water analyses based on chemical analysis (Hitchon and Brulotte, 1994).

Criteria for Rejection	Possible Causes
Any Ca, Mg, Cl, or SO_4 with missing or zero values	Incomplete analysis; insufficient sample; very low content, thus difficultly in determination
Mg $\geq$ Ca	Signifies loss of CO^2 and precipitation of $CaCO^3$ before analysis; very low Ca+Mg, thus difficulty in determination; incorrect entry of Ca+Mg as equivalent Ca as separate Ca and Mg values
OH reported	Wash from cement job; poor analysis
CO3 reported	Contamination from drilling mud; poor sampling of separator or treater
Na (calculated) is negative	Poor analysis
Density < 1.0	Poor determination; organic matter contamination

Table 3. Polynomial fit correlating formation temperature to density of CO2 –saturated brine. This polynomial correlates temperature, pressure, and depth to the Oriskany model brine of Dilmore et al. (2008).

$$\delta = a_0 + a_1T + a_2T^2 + a_3T^3 + a_4T^4$$

$R_2 = 0.9996$

	Value	95% confidence
a_0	1.13261	0.009947
a_1	0.0012873	0.0001723
a_2	-3.46E-05	5.048E-06
a_3	3.144E-07	6.058E-08
a_4	-1.161E-09	2.55E-10

Table 4. Polynomial fit correlating temperature to formation CO2 concentration. This polynomial correlates temperature, pressure, and depth to Oriskany CO2 concentration (Dilmore et al., 2008).

$$mCO_2 = a_0 + a_1T + a_2T^2 + a_3T^3 + a_4T^4 + a_5T^5 + a_6T^6 + a_7T^7 + a_8T^8$$

R_2 = 09991

	Value	95% confidence
a_0	-4.874733	1.094567
a_1	0.5667273	0.2017776
a_2	-0.0223232	0.015391
a_3	0.0003551	0.0006366
a_4	6.069E-07	1.568E-05
a_5	-1.045E-07	2.364E-07
a_6	1.537E-09	2.14E-09
a_7	-9.701E-12	1.068E-11
a_8	2.346E-14	2.254E-14

Appendix I

Oriskany Sandstone Formation Temperature Data

Oriskany Sandstone formation temperature data.

API Number	Source	Formation	Latitude	Longitude	GL Elevation (m)	Depth to Top of Formation (m)	Temperature (°C)
3109713796	C	Oriskany			423	741	24.4
3100723083	C	Oriskany			433	741	24.0
3110112960	C	Oriskany			404	911	27.8
3102322818	C	Oriskany			509	822	27.8
3700920061	C	Oriskany			396	1289	28.3
3110112923	C	Oriskany			552	1110	30.0
3100313684	C	Oriskany			555	960	32.8
3110112972	C	Oriskany			587	1271	35.6
3100311762	C	Oriskany			612	1361	36.3
3110110036	C	Oriskany			616	1403	36.7
Chesapeake-1	C	Oriskany			878	2821	36.0
3408100651	C	Oriskany			360	1517	40.6
4707500020	C	Oriskany	38.60889	-79.64920	1088	1783	42.2
3110113578	C	Oriskany			699	1497	43.3
3700900024	C	Oriskany			359	1611	43.3
3100915731	C	Oriskany			529	1234	45.0
3711702007	C	Oriskany			489	1566	45.0
4707500023	C	Oriskany	38.53760	-79.67849	1027	1573	46.1
4703901018	C	Helderberg	38.25858	-81.63494	244	1599	46.1
Chesapeake-2	C	Oriskany			740	1740	46.7
3700920059	C	Oriskany			470	1975	48.3
3408100412	C	Oriskany			360	1748	48.9
4707500050	C	Oriskany	38.61832	-79.64532	1145	1872	50.0
Chesapeake-3	C	Oriskany			731	1869	50.0
4709702415	C	Oriskany	38.83397	-80.32758	371	2431	55.0
4706101316	C	Huntersville	39.57071	-79.85469	474	2373	55.6
3706300694	C	Huntersville			471	2390	58.9
3705120506	C	Huntersville			765	2363	59.4
4702300012	C	Oriskany	39.08072	-79.26823	815	2632	60.6
4702300021	C	Oriskany	39.07782	-79.25428	611	2643	60.6

API Number	Source	Formation	Latitude	Longitude	GL Elevation (m)	Depth to Top of Formation (m)	Temperature (°C)
4707700316	C	Oriskany	39.53456	-79.85094	566	2412	62.8
4705700022	C	Oriskany	39.40201	-79.40201	585	2624	62.8
4709703017	C	Oriskany	38.86339	-80.28058	532	2333	62.8
4705700037	C	Oriskany	39.35977	-79.06115	393	3020	64.4
4707700126	C	Oriskany	39.50392	-79.87606	585	2372	65.6
4707100010	C	Helderberg	38.91014	-79.34745	769	2758	65.6
4708300904	C	Oriskany	38.62224	-79.88941	1131	2612	65.6
4707100013	C	Helderberg	38.74623	-79.46240	877	2498	67.8
4706101313	C	Huntersville	39.57869	-79.90216	476	2336	67.8
3706300083	C	Oriskany			434	2282	67.8
3705120245	C	Oriskany			861	2625	68.3
4706101314	C	Oriskany	39.48041	-79.90567	565	2373	68.9
4706101311	C	Oriskany	39.60723	-79.85506	603	2432	68.9
4705700016	C	Helderberg	39.41304	-79.03553	570	2665	68.9
4702300026	C	Helderberg	39.20456	-79.20871	882	3016	70.0
3705120507	C	Oriskany			831	2708	70.0
4707100012	C	Helderberg	38.79632	-79.42260	824	2606	71.1
4707700345	C	Helderberg	39.62094	-79.67229	0	2474	72.2
3706300382	C	Oriskany			469	2344	73.3
3711100019	C	Oriskany			740	2589	74.4
4705700059	C	Helderberg	39.45472	-79.04226	722	3182	76.7
4707100014	C	Helderberg	38.85570	-79.39910	856	2798	78.3
Chesapeake-4	C	Oriskany			411	2138	73.0

Source: C—Chesapeake Energy

All data used in this study are available on the West Virginia GIS Technical Center website http://wvgis.wvu.edu.

Appendix II

Oriskany Sandstone Formation Pressure Data

Oriskany Sandstone formation pressure data

API Number	Source	Formation	Latitude	Longitude	GL Elevation (m)	Depth to Top Oriskany (m)	Pressure (kPa)
3400720085	A	Oriskany	41.74362	-80.55750	305	719	6571
3400720097	A	Oriskany	41.74252	-80.57179	305	718	6447
3409320696	A	Oriskany	41.34812	-82.02845	234	394	3241
3410320357	A	Oriskany	41.20962	-81.69461	289	580	5137
3410320396	A	Oriskany	41.21446	-81.69365	374	648	4895
3410320399	A	Oriskany	41.21684	-81.69517	376	662	7412
3410320405	A	Oriskany	41.21468	-81.68951	334	617	7584
3410320571	A	Oriskany	41.20426	-81.70448	298	593	7929
3410320591	A	Oriskany	41.20837	-81.70214	297	622	6929
3410521463	A	Oriskany	38.93080	-81.79015	178	1290	9791
3413320341	A	Oriskany	41.04369	-81.20816	369	925	7446
3415320249	A	Oriskany	41.21769	-81.63165	361	644	4137
3415320255	A	Oriskany	41.21742	-81.63381	363	659	4675
3415320256	A	Oriskany	41.21965	-81.63129	358	642	4482
3415320260	A	Oriskany	41.22003	-81.63468	367	662	4137
3415320265	A	Oriskany	41.21837	-81.63459	366	663	4661
3415320268	A	Oriskany	41.22252	-81.63418	360	654	3654
3415320272	A	Oriskany	41.21872	-81.63567	382	666	2930
3415320275	A	Oriskany	41.22036	-81.63566	370	664	2689
3415320276	A	Oriskany	41.21855	-81.63773	383	664	2758
3415320302	A	Oriskany	41.22728	-81.63253	351	643	4206
4700100619	B	Oriskany	39.06838	-80.02232	626	2432	6895
4700101504	B	Oriskany	39.04357	-80.00167	637	2410	18961
4700500602	B	Oriskany	38.19251	-81.64889	321	1421	6412
4700500900	B	Oriskany	37.97344	-81.95055	351	1315	3034
4700501056	B	Oriskany	37.96331	-81.79329	326	1601	3689

API Number	Source	Formation	Latitude	Longitude	GL Elevation (m)	Depth to Top Oriskany (m)	Pressure (kPa)
4700702305	B	Oriskany	38.75408	-80.63760	336	2160	9653
4701501915	B	Oriskany	38.57948	-81.01992	267	1870	4426
4701702556	B	Oriskany	39.33029	-80.77613	243	2100	14824
4702103376	B	Oriskany	38.96374	-80.81037	287	2052	16892
4702104270	B	Oriskany	38.94324	-80.82175	265	1985	9997
4702104374	B	Oriskany	38.91667	-80.98674	238	1883	12928
4702104886	B	Oriskany	38.96807	-80.89654	220	1899	16616
4702104892	B	Oriskany	38.97533	-80.84726	241	1940	10411
4702105055	B	Oriskany	38.97170	-80.82360	346	2044	11549
4702105355	B	Oriskany	39.03789	-80.81083	350	2115	10515
4702300007	C	Oriskany	39.95471	-79.32992	825	2563	20684
4702300008	C	Oriskany	39.12748	-79.24653	796	2448	22063
4702300009	C	Oriskany	39.96604	-79.32082	834	2508	17554
4702300013	C	Oriskany	39.09597	-79.27809	904	2650	20133
4702300015	C	Oriskany	39.05692	-79.27511	765	2423	17554
4702300017	C	Oriskany	39.02178	-79.29464	868	2582	19650
4702300022	B	Oriskany	39.16420	-79.22622	818	2576	13169
4702300023	V	Oriskany	39.10715	-79.26953	829	2557	14548
4702300024	B	Oriskany	39.06998	-79.27604	841	2586	8963
4702300030	V	Oriskany	39.28557	-79.15300	814	2833	23856
4702300033	B	Oriskany	39.10337	-79.26153	665	2381	9997
4702700003	B	Oriskany	39.31606	-78.63784	409	1708	14479
4702700004	B	Oriskany	39.30024	-78.65259	367	1465	14134
4702700008	B	Oriskany	39.30997	-78.64493	390	1609	13652
4702700009	B	Oriskany	39.29400	-78.65203	381	1551	13927
4702700010	B	Oriskany	39.29487	-78.64829	363	1695	12755
4702700013	B	Oriskany	39.44803	-78.54971	277	1569	11170
4702700015	B	Oriskany	39.38111	-78.59530	300	1630	13748

API Number	Source	Formation	Latitude	Longitude	GL Elevation (m)	Depth to Top Oriskany (m)	Pressure (kPa)
4702700016	B	Oriskany	39.35992	-78.60877	348	1743	13431
4702700017	B	Oriskany	39.35034	-78.62691	342	1598	13790
4702700019	B	Oriskany	39.44862	-78.54133	207	1636	5171
4702700021	B	Oriskany	39.36964	-78.60054	328	1665	13128
4702700022	B	Oriskany	39.16828	-78.77106	535	1970	15169
4702700024	B	Oriskany	39.18540	-78.75317	576	1942	15031
4702700025	B	Oriskany	39.25859	-78.68384	438	1570	13548
4702700026	B	Oriskany	39.24536	-78.69257	477	1758	8274
4702700029	B	Oriskany	39.36717	-78.60596	324	1689	11135
4702700030	B	Oriskany	39.37777	-78.59867	310	1664	12411
4702900120	B	Oriskany	40.58029	-80.62135	306	1422	10342
4703100005	B	Oriskany	38.99129	-78.85617	631	2128	15720
4703100006	B	Oriskany	39.00321	-78.83798	569	2084	15927
4703100008	B	Oriskany	38.97794	-78.86936	515	2022	15927
4703100009	B	Oriskany	39.01353	-78.84140	626	2060	15927
4703100010	B	Oriskany	39.02573	-78.83439	635	2094	15927
4703100012	B	Oriskany	39.03441	-78.82273	561	1906	15927
4703100016	B	Oriskany	38.93801	-78.90081	674	2025	13452
4703100017	B	Oriskany	39.05314	-78.81101	500	2008	9929
4703100018	B	Oriskany	39.15433	-78.78466	544	2100	15479
4703100019	B	Oriskany	39.14054	-78.79465	571	1953	14817
4703304176	B	Oriskany	39.43714	-80.35727	337	2279	7240
4703500038	B	Oriskany	38.59916	-81.64576	224	1529	12893
4703500040	B	Oriskany	38.59679	-81.64258	271	1570	12411
4703500043	B	Oriskany	38.96845	-81.64775	201	1434	13100
4703500045	B	Oriskany	38.59794	-81.63216	279	1593	12411
4703500051	B	Oriskany	38.59050	-81.60731	238	1549	12617
4703500061	B	Oriskany	38.59373	-81.58377	212	1527	10549

API Number	Source	Formation	Latitude	Longitude	GL Elevation (m)	Depth to Top Oriskany (m)	Pressure (kPa)
4703500106	B	Oriskany	38.57438	-81.62234	247	1551	8274
4703500118	B	Oriskany	38.83296	-81.66288	245	1536	12859
4703500157	B	Oriskany	38.79664	-81.64842	257	1573	12859
4703500173	B	Oriskany	38.88753	-81.63591	284	1593	10411
4703500227	B	Oriskany	38.79269	-81.62356	283	1594	12617
4703500431	B	Oriskany	38.83517	-81.62202	285	1604	8687
4703500796	B	Oriskany	38.84914	-81.76850	193	1390	9791
4703500864	B	Oriskany	39.05026	-81.74749	268	1359	9239
4703500978	B	Oriskany	39.03703	-81.67609	296	1455	11652
4703501330	B	Oriskany	38.71363	-81.77915	221	1473	9997
4703900043	B	Oriskany	38.24173	-81.65463	283	1408	8619
4703900074	B	Oriskany	38.25030	-81.57351	228	1388	8825
4703900142	B	Oriskany	38.29777	-81.53461	291	1471	8929
4703900238	B	Oriskany	38.28876	-81.52872	383	1559	6619
4704100049	B	Oriskany	39.08029	-80.53051	372	2105	15065
4704300182	B	Oriskany	38.12632	-82.02903	272	1294	2565
4704500223	B	Oriskany	38.01329	-81.97725	299	1245	3034
4704901077	B	Oriskany	39.54022	-80.31284	375	2414	12411
4705300106	B	Oriskany	38.82912	-81.89039	215	1295	8274
4705700002	B	Oriskany	39.43498	-79.02188	560	2659	16203
4705700016	B	Oriskany	39.41304	-79.03553	570	2591	25049
4705700022	B	Oriskany	39.40201	-79.04544	585	2609	24594
4705700023	B	Oriskany	39.36892	-78.86400	284	547	3275
4705700030	B	Oriskany	39.37342	-78.87878	242	479	3172
4705900641	C	Oriskany	37.63161	-81.87895	350	1657	7412
4705900786	B	Oriskany	37.65175	-81.90393	472	1757	5033
4705900850	B	Oriskany	37.63898	-81.85055	545	1865	5792
4706100289	B	Oriskany	39.52218	-79.88317	660	2361	24132

API Number	Source	Formation	Latitude	Longitude	GL Elevation (m)	Depth to Top Oriskany (m)	Pressure (kPa)
4706100335	B	Oriskany	39.56205	-79.85628	668	2489	21029
4706100568	B	Oriskany	39.61146	-79.84536	634	2443	24132
4706100599	B	Oriskany	39.46408	-79.90737	571	2355	22408
4706101057	B	Oriskany	39.69063	-79.78303	637	2366	21719
4706101078	B	Oriskany	39.52454	-79.92791	511	2326	20340
4706101246	B	Oriskany	39.55068	-79.91704	465	2290	16375
4706101282	B	Oriskany	39.58872	-79.87474	599	2480	11032
4706101368	B	Oriskany	39.47054	-79.95332	521	2335	18961
4706101373	B	Oriskany	39.59786	-79.86275	436	2193	21029
4706101395	B	Oriskany	39.62094	-79.84195	597	2356	24132
4706500003	B	Oriskany	39.58553	-78.43412	168	1438	13790
4706500004	B	Oriskany	39.58524	-78.43787	169	1362	13672
4707100013	B	Oriskany	38.74623	-79.46240	877	2323	13100
4707100016	B	Oriskany	38.66464	-79.54145	1113	2467	15741
4707301314	B	Oriskany	39.44440	-81.08932	280	1829	14183
4707500004	B	Oriskany	38.65302	-79.76943	982	1729	12728
4707500010	B	Oriskany	38.70238	-79.74812	1067	1805	13686
4707500024	B	Oriskany	38.51307	-79.69530	1173	1739	11307
4707500049	B	Oriskany	38.53252	-79.69068	1024	1814	7998
4707500050	C	Oriskany	38.61832	-79.64532	1139	1792	8791
4707700005	B	Oriskany	39.43231	-79.56575	608	1850	15996
4707700010	B	Oriskany	39.42047	-79.57452	579	1576	14755
4707700013	C	Oriskany	39.43387	-79.57246	656	1649	12928
4707700017	B	Oriskany	39.41231	-79.58019	613	1551	12907
4707700020	C	Oriskany	39.40810	-79.58169	669	1600	10315
4707700025	B	Oriskany	39.42672	-79.57357	703	1703	10342
4707700028	B	Oriskany	39.41481	-79.57501	639	1598	10480
4707700061	B	Oriskany	39.26999	-79.49884	776	1500	12928

API Number	Source	Formation	Latitude	Longitude	GL Elevation (m)	Depth to Top Oriskany (m)	Pressure (kPa)
4707700065	B	Oriskany	39.26415	-79.50349	775	1518	7929
4707700068	B	Oriskany	39.36778	-79.60068	573	1524	9101
4707700094	B	Oriskany	39.34118	-79.62855	738	1832	11859
4707700127	B	Oriskany	39.50814	-79.86406	594	2469	23773
4707700253	B	Oriskany	39.49681	-79.49873	839	2191	19305
4707700284	B	Oriskany	39.70282	-79.76389	713	2368	22408
4707700319	B	Oriskany	39.46923	-79.85708	529	2353	18961
4707700320	B	Oriskany	39.58072	-79.69065	625	2464	15169
4707700321	B	Oriskany	39.48607	-79.88734	554	2321	22408
4707900204	B	Oriskany	38.61315	-81.74124	272	1530	11783
4707900221	B	Oriskany	38.52532	-81.78736	229	1458	5102
4707900228	B	Oriskany	38.64781	-81.72138	296	1581	6826
4707900241	B	Oriskany	38.66974	-81.74790	225	1491	5585
4707900246	B	Oriskany	38.66605	-81.74186	216	1487	11721
4707900249	B	Oriskany	38.64331	-81.72988	236	1515	7963
4707900272	B	Oriskany	38.66052	-81.74561	237	1507	9377
4707900324	B	Oriskany	38.60387	-81.77001	218	1470	12617
4707900348	B	Oriskany	38.58452	-81.76726	301	1549	12617
4707900380	B	Oriskany	38.56826	-81.77225	242	1483	12135
4707900394	B	Oriskany	38.55994	-81.77824	312	1529	11032
4707900410	B	Oriskany	38.55217	-81.78076	267	1515	10273
4707900431	B	Oriskany	38.54985	-81.77661	252	1494	7998
4707900441	B	Oriskany	38.54844	-81.78515	249	1487	7722
4707900452	B	Oriskany	38.56245	-81.78184	273	1511	6205
4707900454	B	Oriskany	38.54215	-81.77804	251	1494	8067
4707900458	B	Oriskany	38.65428	-81.76888	226	1488	10790
4707900459	B	Oriskany	38.55093	-81.79691	213	1439	7929
4707900469	B	Oriskany	38.53818	-81.78196	253	1497	7757

API Number	Source	Formation	Latitude	Longitude	GL Elevation (m)	Depth to Top Oriskany (m)	Pressure (kPa)
4707900487	B	Oriskany	38.54186	-81.78694	148	1516	5654
4707900531	B	Oriskany	38.52919	-81.79241	264	1511	5688
4707900545	B	Oriskany	38.50252	-87.78278	273	1488	7929
4707900553	B	Oriskany	38.50569	-81.93484	202	1334	4826
4707900556	B	Oriskany	38.49576	-81.78308	251	1459	8101
4707900577	B	Oriskany	38.46775	-81.79156	197	1396	11583
4707900583	B	Oriskany	38.45872	-81.77006	175	1369	12135
4707900692	B	Oriskany	38.63824	-81.74452	291	1555	6550
4708300047	B	Oriskany	38.79123	-79.68743	925	1479	13445
4708300058	B	Oriskany	38.75454	-79.71322	962	1475	14100
4708300078	B	Oriskany	38.73795	-79.72924	969	1590	13417
4708300082	B	Oriskany	38.90044	-79.62398	888	1844	11032
4708300084	B	Oriskany	38.77280	-79.70870	921	1477	13927
4708300087	B	Oriskany	38.80478	-79.68319	940	1588	13859
4708300091	B	Oriskany	38.72385	-79.74255	1016	1712	13445
4708300097	C	Oriskany	38.81316	-79.67742	903	1608	10315
4708300099	B	Oriskany	38.83169	-79.66509	1005	1907	8101
4708300122	B	Oriskany	38.75168	-79.71829	1088	1641	11514
4708300386	B	Oriskany	38.65882	-80.23757	849	2326	8619
4708300545	B	Oriskany	38.60642	-79.86381	1134	2501	10687
4708300711	C	Oriskany	38.67844	-79.85813	1106	2540	15858
4708300822	B	Oriskany	38.96168	-79.50501	668	2112	18382
4708300846	B	Oriskany	38.97446	-79.49863	668	2118	17237
4708300884	B	Oriskany	38.76525	-79.58263	961	2266	14479
4708300904	C	Oriskany	38.62224	-79.88941	1131	2503	16548
4708301033	B	Oriskany	38.63604	-79.89017	1143	2518	19650
4708301173	B	Oriskany	38.94324	-80.05988	698	2359	11032
4708701575	B	Oriskany	38.65070	-81.28627	274	1722	8274

API Number	Source	Formation	Latitude	Longitude	GL Elevation (m)	Depth to Top Oriskany (m)	Pressure (kPa)
4708703853	B	Oriskany	38.78615	-81.30650	277	1784	7240
4708703856	B	Oriskany	38.78020	-81.31020	317	1819	6895
4708704031	B	Oriskany	38.69498	-81.25259	317	1795	6895
4708704050	B	Oriskany	38.74623	-81.23350	280	1795	6895
4709300001	B	Oriskany	39.08044	-79.39784	1020	2429	22063
4709300002	C	Oriskany	39.06310	-79.40547	1019	2515	20684
4709300003	B	Oriskany	39.09771	-79.38746	1005	2455	15720
4709300022	B	Oriskany	39.23074	-79.75269	552	1347	13341
4709300027	B	Oriskany	39.23737	-79.74728	506	1305	11032
4709300030	B	Oriskany	39.24594	-79.74150	587	1412	10983
4709300050	B	Oriskany	39.04542	-79.43951	986	2531	7584
4709300054	B	Oriskany	39.02351	-79.44327	1000	2505	16203
4709500976	B	Oriskany	39.50016	-81.08138	191	1710	14348
4709702777	B	Oriskany	38.82956	-80.39057	500	2252	7584
4709703022	B	Oriskany	38.84249	-80.32837	539	2204	16892
4710300645	B	Oriskany	39.67814	-80.82395	411	2091	13790
4710700169	B	Oriskany	39.33246	-81.47625	205	1439	7584
4710700288	B	Oriskany	39.04734	-81.55841	311	1629	12928
4710700320	B	Oriskany	39.08393	-81.54036	261	1529	7446
4710700375	B	Oriskany	39.21430	-81.70654	269	1326	10756
4710700384	B	Oriskany	39.20893	-81.69928	259	1329	10756
4710700385	B	Oriskany	39.20108	-81.72343	213	1257	11549
4710700386	B	Oriskany	39.19788	-81.72976	189	1230	11549
4710700387	B	Oriskany	39.21168	-81.69182	214	1293	11170
4710700391	B	Oriskany	39.20442	-81.69667	235	1312	11170
4710700392	B	Oriskany	39.19730	-81.71132	190	1250	11445
4710700395	B	Oriskany	39.19077	-81.70412	200	1269	10894
4710700611	B	Oriskany	39.19812	-81.42551	235	1595	9308

API Number	Source	Formation	Latitude	Longitude	GL Elevation (m)	Depth to Top Oriskany (m)	Pressure (kPa)
4710701053	B	Oriskany	39.26830	-81.65673	194	1275	10342
4710701303	B	Oriskany	39.14461	-81.54390	195	1451	8274
4710701309	B	Oriskany	39.24811	-81.60812	205	1331	5171

Source: A—Ohio Stat Division of Natural Resources website http://www.dnr.state.oh.us
B—West Virginia Geologic and Economic Survey website http://www.wvgs.wvnet.edu
C—Chesapeake Energy

All data used in this study are available on the West Virginia GIS Technical Center website http://wvgis.wvu.edu.

Appendix III

Oriskany Sandstone Geochemical Data

Oriskany Sandstone geochemical data.

Sample/API Number	Source	Horizon	Latitude	Longitude	GL Elevation (m)	Depth/Top (m)	Depth/Base (m)	TDS Calculated (mg/L)
3407321971	C	Oriskany	39.51075	-82.5557	340	665		194292
3705120737	C	Oriskany	39.78439	-79.75071				341633
3711720158	C	Oriskany	41.76024	-76.99193	522	2038		385500
3711720159	C	Oriskany	41.45374	-76.59301	523	2039		277375
4700500567	C	Oriskany	38.20717	-81.65403	299	1393	1397	246321
4700700226	H	Oriskany	38.68439	-80.82756	352	1914		246819
4700700447	J	Oriskany	38.79923	-80.55487	269	2101		80000
4701502426	C	Oriskany	38.38474	-81.25295	436	1900	1909	222949
4702300005	C	Oriskany	39.04240	-79.28571	912	2525	2622	102548
4702300007	C	Oriskany	39.95471	-79.32992	825	2563	2624	187404
4702300008	C	Oriskany	39.12748	-79.24653	796	2448	2558	23908
4702300009	C	Oriskany	39.96604	-79.32082	834	2508		128344
4702300010	C	Oriskany	39.14823	-79.23740	805	2504	2611	204038
4702300011	C	Oriskany	39.18613	-79.21765	879	2716	2789	90079
4702300012	C	Oriskany	39.08072	-79.26823	815	2524	2586	110545
4702300013	C	Oriskany	39.09597	-79.27809	904	2650	2710	197705
4702300014	C	Oriskany	39.11528	-79.25558	645	2319	2382	207709
4702300015	C	Oriskany	39.05692	-79.27511	765	2423	2488	35011
4702300017	C	Oriskany	39.02178	-79.29464	868	2582		163637
4702300018	C	Oriskany	39.06824	-79.26191	698	2376	2443	22236
4702300019	C	Oriskany	39.26119	-79.18189	959	2973	3042	188919.3
4702300020	C	Oriskany	39.07332	-79.29409	1055	2830	2891	166400
4702300021	C	Oriskany	39.07782	-79.25428	611	2381		13091
4702300023	C	Oriskany	39.10715	-79.26953	829	2557	2621	249278
4702300030	C	Oriskany	39.28557	-79.15300	814	2833		83778
4702300032	C	Oriskany	39.09612	-79.24944	596	2359	2390	17594
4703100016	*	Oriskany	38.93801	-78.90081	674	2025	2096	29655
4703500022	H	Oriskany	38.69528	-81.54256	296	1677	1680	266694
4703500024	H	Oriskany	38.65926	-81.54996	300	1659		266019
4703500041	H	Oriskany	38.59932	-81.63977	200	1512		138199

Sample/API Number	Source	Horizon	Latitude	Longitude	GL Elevation (m)	Depth/Top (m)	Depth/Base (m)	TDS Calculated (mg/L)
4703500053	H	Oriskany	38.57157	-81.59830	254	1555		259914
4703500077	H	Oriskany	38.57535	-81.64983	288	1609		268146
4703500094	C	Oriskany	38.60634	-81.65371	213	1509		338377
4703500103	H	Oriskany	38.94282	-81.58816	204	1546		264713
4703500104	C	Oriskany	38.60925	-81.62882	276	1586		92342
4703500112	H	Oriskany	38.95341	-81.62567	211	1523		262276
4703500198	H	Oriskany	38.86180	-81.61973	211	1644		275968
4703500223	H	Oriskany	38.82898	-81.61559	195	1532		175678
4703500224	H	Oriskany	38.61543	-81.58049	208	1543		239231
4703500225	C	Oriskany	38.61878	-81.64038	234	1536		315133
4703500272	C	Oriskany	38.74753	-81.63530	256	1579		270117
4703500273	C	Oriskany	38.74394	-81.64003	269	1589		278947
4703500308	H	Oriskany	38.91959	-81.60821	235	1579		239793
4703500312	H	Oriskany	38.79386	-81.61874	213	1549		267695
4703500332	H	Oriskany	38.86413	-81.59392	213	1597		241390
4703500337	H	Oriskany	38.91623	-81.61323	285	1628		226768
4703500381	H	Oriskany	38.63067	-81.64995	248	1561		264309
4703500398	H	Oriskany	38.78094	-81.62115	273	1610		267683
4703500413	C	Oriskany	38.77699	-81.62970	303	1625		178745
4703500419	C	Oriskany	38.76065	-81.64656	190	1503	1519	342271
4703500441	H	Oriskany	38.75161	-81.62059	253	1590		270323
4703500486	C	Oriskany	38.8843	-81.6815	201	1481	1498	55722
4703500512	C	Oriskany	38.83755	-81.6789	208	1502		217147
4703500531	C	Oriskany	38.85337	-81.6947	225	1504		148323
4703500911	C	Oriskany	38.88024	-81.6954	223	1498		99380
4703502408	C	Oriskany	38.8239	-81.6811	225	1512		202822
4703502464	C	Oriskany	38.84409	-81.6985	184	1462	1472	82199
4703900222	I	Oriskany	38.27818	-81.50221	345	1550	1551	238989
4703900226	I	Oriskany	38.43875	-81.35657	382	1761		262164
4703900269	I	Oriskany	38.26830	-81.50828	405	1600		233580
4703900321	H	Oriskany	38.44919	-81.57264	280	1523		271551
4703900458	H	Oriskany	38.44615	-81.58850	305	1561		264280

Sample/API Number	Source	Horizon	Latitude	Longitude	GL Elevation (m)	Depth/Top (m)	Depth/Base (m)	TDS Calculated (mg/L)
4703900513	H	Oriskany	38.45065	-81.59200	315	1569		266696
4703900696	H	Oriskany	38.52934	-81.66645	261	1539		253625
4703900754	H	Oriskany	38.47315	-81.44838	223	1589		273093
4703900771	C	Oriskany	38.56897	-81.64680	232	1537	1551	347133
4703900926	H	Oriskany	38.45166	-81.65561	217	1478		259923
4703901352	C	Oriskany	38.52411	-81.4859	260	1581	1594	51230
4703901533	C	Oriskany	38.44865	-81.4375	307	1654		92283
4703905269	C	Oriskany	38.442513	-81.403	368	1706	1718	129349
4705300260	C	Oriskany	38.77570	-82.07207	211			216847
4705500014	C	Oriskany	37.35613	-81.18628	794	2385	2432	77000
4705700022	C	Oriskany	39.40201	-79.04544	585	2609		222
4705900641	C	Oriskany	37.63161	-81.87895	350	1657	1661	48245
4706100337	*	Oriskany	39.58848	-79.83815	608	2471		279860
4706100347	*	Oriskany	39.56573	-79.88614	626	2446	2463	271200
4706900038	C	Oriskany	40.05866	-80.58205	396	2060	2087	216847
4707100010	C	Oriskany	38.91014	-79.34745	769	2594	2665	185867
4707100012	C	Oriskany	38.79632	-79.42260	824	2458	2552	76479
4707500011	C	Oriskany	38.67495	-79.75759	1052	1750	1809	28441
4707500014	C	Oriskany	38.63024	-79.78072	984	1815	1870	195659
4707500025	*	Oriskany	38.68381	-79.75481	1048	1771	1832	282995
4707500026	C	Oriskany	38.66391	-79.7635	1072	1794	1863	21691
4707500033	*	Oriskany	38.65999	-79.7655	1014	1740	1800	37090
4707500034	C	Oriskany	38.66769	-79.76184	1063	1806		42737
4707700013	C	Oriskany	39.43387	-79.57246	656	1649	1699	89348
4707700021	C	Oriskany	39.41043	-79.57720	685			122512
4707700025	*	Oriskany	39.42672	-79.57357	703			176969
4707700058	C	Oriskany	39.40331	-79.59137	536	1419	1451	259414
4707700090	H	Oriskany	39.35337	-79.60835	784	1835	1875	
4707700141	C	Oriskany	39.38034	-79.58653	610	1609	1649	30887
4707700143	C	Oriskany	39.36482	-79.60156	680	1651	1690	313023
4707700155	C	Oriskany	39.38197	-79.58294	610	1603	1644	198626
4707700156	C	Oriskany	39.37754	-79.59483	631	1568	1608	340920

Sample/API Number	Source	Horizon	Latitude	Longitude	GL Elevation (m)	Depth/Top (m)	Depth/Base (m)	TDS Calculated (mg/L)
4707700158	C	Oriskany	39.36237	-79.59397	775	1810	1851	130370
4707700162	*	Oriskany	39.35409	-79.62037	617	1611	1650	324460
4707700164	C	Oriskany	39.33534	-79.62316	794	1953	1993	202318
4707700166	C	Oriskany	39.42145	-79.54762	815	2010	2046	255943
4707700186	*	Oriskany	39.51110	-79.83121	540	2368	2391	292200
4707700316	C	Oriskany	39.53456	-79.85094	566	2358	2393	255943
4707900031	C	Oriskany	38.42908	-81.85005	180	1321	1322	114035
4707900204	H	Oriskany	38.61311	-81.74124	272	1547		266039
4708100289	C	Oriskany	37.828689	-81.31032	548	2000	2004	75000
4708300002	H	Oriskany	38.78442	-79.91600	619	1135	1153	107840
4708300096	C	Oriskany	38.75422	-79.723	990	1572		3622
4708300097	C	Oriskany	38.81316	-79.67742	903	1608		97453
4708300118	C	Oriskany	38.78203	-79.69855	987	1516	1576	136876
4708300124	C	Oriskany	38.74918	-79.7216	1061	1624	1698	1836
4708300126	C	Oriskany	38.79111	-79.69454	985	1601	1664	185113
4708300612	C	Oriskany	38.75186	-80.11867	945			225130
4708300904	C	Oriskany	38.62224	-79.88941	1131	2503	2559	191039
4708700239	I	Oriskany	38.61978	-81.14033	314	1822		222755
4708700413	H	Oriskany	38.55924	-81.39392	309	1676		275327
4708700429	H	Oriskany	38.60787	-81.51940	207	1544		272738
4708701200	J	Oriskany	38.60874	-81.31771	279	1682		37000
4708900005	C	Oriskany	37.69236	-80.95206	553	2128	2134	38000
4709300002	C	Oriskany	39.06310	-79.40547	1019	2515	2554	230964
4709702852	C	Oriskany	38.69745	-80.28997	812	2370	2436	253721
4709900393	H	Oriskany	38.23142	-82.55329	231	928		121699
4710500068	I	Oriskany	38.99318	-81.30763	254	1494	1495	274294
4710500091	H	Oriskany	39.02368	-81.30413	265	1488		
4710500171	H	Oriskany	38.91115	-81.36267	246	1724		255999
4710500531	J	Oriskany	38.95428	-81.29141	320	1807	1818	294197
4710700306	C	Oriskany	39.05808	-81.5502	329	1640		222516
4710700336	C	Oriskany	39.07782	-81.5357	300	1598		226438
4710700346	C	Oriskany	39.07985	-81.53311	290	1586		235513

Sample/API Number	Source	Horizon	Latitude	Longitude	GL Elevation (m)	Depth/Top (m)	Depth/Base (m)	TDS Calculated (mg/L)
4710700351	J	Oriskany	39.25698	-81.27240	324	1323		190000
ED-82-37	F	Oriskany	39.97139	-79.09139	646	2694	2727	101000
ED-82-38	F	Oriskany	39.94111	-79.11944	570	2676	2695	230000
ED-82-39	F	Oriskany	39.93361	-79.11056	642	2697	2729	302000
ED-82-40	F	Oriskany	40.04167	-78.91667	718	2604	2627	343000
Maryland_GARCO_G41	M	Oriskany	39.65722	-79.325	603	2128	2166	305380
Maryland_WASCO_AC2	M	Oriskany	39.70416	-78.22916	189	42	43	113
Maryland-153	*	Oriskany	39.665	-79.2361	893	2588	2632	130960
NewYork_1	L	Oriskany	42.05	-78.62		1246	1252	254534
NewYork_2	L	Oriskany	42.11	-78.17		1430	1436	306509
NewYork_3	L	Oriskany	42.17	-78.00		1169	1170	321261
NewYork_4	L	Oriskany	42.17	-77.92		1169	1181	318570
NewYork_5	L	Oriskany	42.052	-77.32		1250		262609
OHIO_12	G	Oriskany	40.85057	-82.08988	357	652		252900
OHIO_18	G	Oriskany	41.31122	-82.09506		384	399	177900
OHIO_21	G	Oriskany	40.40286	-80.71155	357	1568	1577	316100
OHIO_243	G	Oriskany	40.91527	-81.76897	290	693		231090
OHIO_244	G	Oriskany	41.76928	-81.28762		457		295700
OHIO_25	G	Oriskany	41.20770	-81.91132		547		273500
OHIO_2545	G	Oriskany	39.74174	-81.65590		1162	1167	292700
OHIO_287	G	Oriskany	41.32416	-81.53710	347	753		197550
OHIO_29	G	Oriskany	40.74705	-82.40302	347	611		165600
OHIO_3	G	Oriskany	40.92303	-82.14164	337	608	613	251200
OHIO_31	G	Oriskany	41.26723	-81.95789	255	463	469	256100
OHIO_32	G	Oriskany	41.15853	-81.64475	318	650	652	246750
OHIO_34	G	Oriskany	41.16371	-81.99154	270	530		257700
OHIO_3477	G	Oriskany	39.65279	-81.51805		1311	1318	285000
OHIO_36	G	Oriskany	41.01102	-82.11317	332	555		224800
OHIO_37	G	Oriskany	40.83763	-82.17269		604		246800
OHIO_38	G	Oriskany	40.86868	-82.28915		515		133700
OHIO_57	G	Oriskany	41.40439	-82.09609	191	337		168750
OHIO_58	G	Oriskany	41.19994	-82.01069	282	475		241900

Sample/API Number	Source	Horizon	Latitude	Longitude	GL Elevation (m)	Depth/Top (m)	Depth/Base (m)	TDS Calculated (mg/L)
OHIO_65-88	G	Oriskany	41.90777	-80.73238	190	494	497	284900
OHIO_709	G	Oriskany	41.82107	-81.00393	205	497	498	319500
PENN_TULLY_1	D	Oriskany	42.07306	-80.06202	272	609	611	272518
PENN_TULLY_176	D	Oriskany	41.03091	-78.84634	450	2213	2221	327262
PENN_TULLY_177	D	Oriskany	41.05477	-78.75641	485	2213	2224	338440
PENN_TULLY_178	D	Oriskany	41.12063	-78.74281	460	2189	2192	324112
PENN_TULLY_179	D	Oriskany	41.23796	-78.62943	533	2241	2250	191311
PENN_TULLY_181	D	Oriskany	41.23262	-78.53979	478	2188	2198	232255
PENN_TULLY_183	D	Oriskany	40.84483	-78.44819	526	2440	2446	253770
PENN_TULLY_183a	D	Oriskany	40.84483	-78.44819	526	2449		330389
PENN_TULLY_185	D	Oriskany	41.06146	-78.81391	472	2270		328338
PENN_TULLY_185a	D	Oriskany	41.06146	-78.81391	472	2211		336042
PENN_TULLY_186	D	Oriskany	41.21724	-78.53979	352	2089	2100	240329
PENN_TULLY_187	D	Oriskany	41.07349	-78.73435	512	2257	2266	274977
PENN_TULLY_189	D	Oriskany	41.07884	-78.72566	487	2207	2216	190401
PENN_TULLY_190	D	Oriskany	41.08218	-78.71630	471	2205	2209	325408
PENN_TULLY_191	D	Oriskany	41.04140	-78.77714	443	2198	2207	325054
PENN_TULLY_192	D	Oriskany	41.05343	-78.81325	450	2212	2221	316299
PENN_TULLY_193	D	Oriskany	39.82755	-78.35384	331	1402	1460	159797
PENN_TULLY_193a	D	Oriskany	39.82755	-78.35384	331	1437		297592
PENN_TULLY_194	D	Oriskany	40.79758	-78.99555	423	2199	2208	319848
PENN_TULLY_195	D	Oriskany	41.38039	-78.33475	516	2089	2089	268721
PENN_TULLY_196	D	Oriskany	40.85196	-79.01606	479	2323	2329	297265
PENN_TULLY_197	D	Oriskany	41.40103	-78.28866	423	2014	2024	325009
PENN_TULLY_198	D	Oriskany	39.76393	-78.38837	333	1515		139277
PENN_TULLY_199	D	Oriskany	40.87603	-78.89214	612	2306		279698
PENN_TULLY_200	D	Oriskany	40.62273	-79.41129	324	2349	2354	303654
PENN_TULLY_201	D	Oriskany	41.86746	-77.49424	500	1325	1331	595
PENN_TULLY_203	D	Oriskany	41.16105	-78.67281	501	2259	2267	274542
PENN_TULLY_204	D	Oriskany	41.06213	-78.73168	449	2187	2189	330058
PENN_TULLY_205	D	Oriskany	41.03781	-78.78422	429	2214		250203
PENN_TULLY_209	D	Oriskany	40.10795	-79.06582	629	2566	2595	127477

Sample/API Number	Source	Horizon	Latitude	Longitude	GL Elevation (m)	Depth/Top (m)	Depth/Base (m)	TDS Calculated (mg/L)
PENN_TULLY_210	D	Oriskany	40.09538	-79.29357	666	2236		315328
PENN_TULLY_211	D	Oriskany	40.09686	-79.07691	647	2594	2606	154357
PENN_TULLY_212	D	Oriskany	40.10647	-79.28839	747	2383	2392	308131
PENN_TULLY_213	D	Oriskany	40.11756	-79.05325	637	2341	2634	172401
PENN_TULLY_214	D	Oriskany	40.12865	-79.04215	621	2615	2637	250199
PENN_TULLY_215	D	Oriskany	40.06506	-79.09540	628	2579	2609	281474
PENN_TULLY_216	D	Oriskany	40.09168	-79.11018	621	2601	2629	220885
PENN_TULLY_217	D	Oriskany	40.16341	-79.14050	753	2477	2479	414614
PENN_TULLY_217a	D	Oriskany	40.16341	-79.14050	753	2455	2479	124060
PENN_TULLY_220a	D	Oriskany	40.00221	-79.33054	843	2470	2501	122695
PENN_TULLY_224	D	Oriskany	41.35134	-80.19413	404	1219	1233	330382
PENN_TULLY_225	D	Oriskany	40.32857	-79.26270	824	2298	2312	277677
PENN_TULLY_227	D	Oriskany	40.22254	-79.38544	640	2539		317284
PENN_TULLY_227a	D	Oriskany	40.22254	-79.38544	640	2539		321308
PENN_TULLY_229	D	Oriskany	40.38876	-78.82247	650	2697	2728	312823
PENN_TULLY_3	D	Oriskany	41.91240	-77.17413	482	1315		276234
PENN_TULLY_4	D	Oriskany	41.67769	-79.39847	500	1321	1326	309560
PENN_TULLY_45	D	Oriskany	40.17965	-79.43499	540	2236	2266	272298
PENN_TULLY_5	D	Oriskany	41.45388	-80.36174	302	977	981	332297
PENN_TULLY_52	D	Oriskany	41.36045	-77.91030	309	1841		345000
PENN_TULLY_56	D	Oriskany	41.91516	-77.16770	482	1315		278048
PENN_TULLY_59	D	Oriskany	40.41272	-80.31738	320	1908	1925	264835
PENN_TULLY_68	D	Oriskany	41.06012	-78.72298	456	2215	2222	248511
PENN_TULLY_69	D	Oriskany	41.14331	-78.61464	502	2296		274763
PENN_TULLY_78	D	Oriskany	40.20258	-79.40985	573	2258		302000
PENN_WEST_1101	E	Oriskany	41.17930	-78.60232	495	2246		312000
PENN_WEST_1102	E	Oriskany	41.07578	-78.71878	456	2215	2222	279000
PENN_WEST_1103	E	Oriskany	41.16474	-78.61849	502	2295	2301	311000
PENN_WEST_1203	E	Oriskany	42.07863	-80.08718	272	609		256000

Sample/API Number	pH	Li (mg/L)	Na (mg/L)	K (mg/L)	Mg (mg/L)	Ca (mg/L)	Sr (mg/L)	Ba (mg/L)	Mn (mg/L)	Fe (mg/L)
3407321971										
3705120737	5.4		86544	3500	3280	33684		5625		

Sample/API Number	pH	Li (mg/L)	Na (mg/L)	K (mg/L)	Mg (mg/L)	Ca (mg/L)	Sr (mg/L)	Ba (mg/L)	Mn (mg/L)	Fe (mg/L)
3711720158	3		112486		729	34085		1875		250
3711720159	4.2		31068	0	5224	63558		1025		
4700500567			61720	4400	4350	22750		1300		
4700700226			69620	2350	2300	19270		880		144
4700700447										
4701502426	2		14223		5711	59259		0		2200
4702300005	4.7		30690	0	1166	6567		1125		
4702300007	5.4		56822	1	1094	12613		2375		130
4702300008	5.6		7578	0	67	1532		80		70
4702300009	5.7		38969	1	1385	8328		462		130
4702300010	5.6		60261	1	1312	15215		2250		80
4702300011	6		27880	1	753	5846		0		200
4702300012	4		21868		608	18819		0		2500
4702300013	4.4		57097	3900	4009	9824		1375		
4702300014	4.8		59219	1	972	18218		1800		40
4702300015	6.9		11144	0	85	1982		550		60
4702300017	6.3		48042		1434	11411		2750		100
4702300018	7.1		7018	1	292	1101		125		100
4702300019	4		58583.3	0	1215	12431		440		
4702300020	6.3		51985	2	729	10811		875		160
4702300021	6.3		4258	1	49	701		83		25
4702300023	4.9		75916	1	1822	16040		3000		
4702300030	6.3		23754	6000	656	3368		0		
4702300032	6.2		2295		109	4070		0		
4703100016			1390	65	35	265				
4703500022			74332	3116	1976	22970		580		50
4703500024			74320	3750	2492	20359	1082	2170		12
4703500041			37200	1900	1350	10450		500		880
4703500053			69450	2900	3800	21900		2000		25
4703500077			71650	5100	2500	23500		1160		120
4703500094	6		99068		2673	27368		0		
4703500103			70000	5300	3000	23100		1025		108
4703500104	6.8		29159		948	5213		0		

Sample/API Number	pH	Li (mg/L)	Na (mg/L)	K (mg/L)	Mg (mg/L)	Ca (mg/L)	Sr (mg/L)	Ba (mg/L)	Mn (mg/L)	Fe (mg/L)
4703500112			69700	4000	3000	23600		42		115
4703500198			78076	194	2820	23600		1100		35
4703500223			48000	2800	1815	14800		440		27
4703500224			64600	6900	2130	19250		250		32
4703500225	2.5		87676		4921	26266		2		
4703500272	4.2		78372		3159	21052		0		
4703500273	6.6		82303		2430	21654		0		
4703500308			65370	4230	2400	20000		1260		45
4703500312			72900	5600	2500	22150		830		60
4703500332			64680	4350	2550	20900		1260		78
4703500337			61000	3850	2400	19500		1600		45
4703500381			72650	3750	2750	22100		830		38
4703500398			71860	4100	2900	23500		1235		20
4703500413	3.5		52132		2551	13032		0		
4703500419	2.5		100744		3645	25864		0		
4703500441			75372	2450	2950	22400		618		45
4703500486										
4703500512										
4703500531										
4703500911										
4703502408										
4703502464										
4703900222			85700	2800	479	3920	1386	850		5
4703900226			69600	4850	2407	22600	1574	990		75
4703900269			81100	689	2580	4540	1331	1532		26
4703900321			98291	1520	2460	19170	Trace	1380		3750
4703900458			72391	3565	2740	22740		750		92
4703900513			72982	3720	2380	23100		1000		131
4703900696			67400	1400	4000	29000		1200		270
4703900754			75270	2600	2200	24000		1800		270
4703900771	3.2		101531		3523	27067		0		
4703900926			70550	4070	2350	22500		2075		80

Sample/API Number	pH	Li (mg/L)	Na (mg/L)	K (mg/L)	Mg (mg/L)	Ca (mg/L)	Sr (mg/L)	Ba (mg/L)	Mn (mg/L)	Fe (mg/L)
4703901352										
4703901533										
4703905269										
4705300260	9.4		51428		4374	24825				
4705500014										
4705700022	5		53		10	16		3		15
4705900641	4.9		13901	0	790	3509		45		
4706100337			52200	2700	1860	24100				
4706100347			50000	2820	1880	23500				
4706900038	9.4		51428		4374	24825		0		
4707100010	5.4		51189	0	1312	15616		4750		850
4707100012	7.4		24598	1	267	4364		500		
4707500011			3839		486	6006		110		
4707500014			48387		9720	12412				
4707500025			83943		2430	21622		0		
4707500026										
4707500033										
4707500034			4386		2673	7608		0		
4707700013			25167		243	8809		4		
4707700021			40850		486	6006		0		
4707700025			8100	246	283	2340				
4707700058			78996		2430	17618		0		
4707700090	4.4		101316		1556	20532				
4707700141			3395		1701	5606		0		
4707700143			97473		2430	20020				
4707700155			65338		1118	10170				
4707700156			108470		2430	20020		0		
4707700158			40204		632	9209		0		
4707700162			102000		2430	20020		0		
4707700164			60320		1701	15215		0		
4707700166	6.4		69218		1701	24424		3600		
4707700186			50200	3470	2530	33000				
4707700316	6.4		69218		1701	24424		3600		

Sample/API Number	pH	Li (mg/L)	Na (mg/L)	K (mg/L)	Mg (mg/L)	Ca (mg/L)	Sr (mg/L)	Ba (mg/L)	Mn (mg/L)	Fe (mg/L)
4707900031			31655	700	1730	8600		1650		
4707900204			68280	3400	3220	26140		1700		18
4708100289										
4708300002			34000	4500	940	3200		167		6.7
4708300096										
4708300097			26905		729	9209		610		
4708300118			28803		4617	16416		0		
4708300124										
4708300126			48755		1701	19620		0		
4708300612			62682		3159	19219		0		
4708300904	6		43516		3499	24024				75
4708700239			62000		2550	17600		1000		
4708700413			76330	4490	1372	24260		100		24.5
4708700429			73850	4550	3200	22500		2500		84
4708701200										
4708900005										
4709300002	4.2		66631	1	2065	18018		2250		
4709702852	3		66053		2066	27227		1375		
4709900393			35340	830	1975	8060				6.3
4710500068			68100	3400	4110	27200	889	1550		115
4710500091			80000		3200	2500		1280		
4710500171			59450	4040	3770	29530		1000		
4710500531	5.9		75727		4100	29160				
4710700306										
4710700336										
4710700346					1562	31120			4	
4710700351										
ED-82-37	5.63	105	24400	978	797	8930	4400	1510	6.2	458
ED-82-38	6.14	277	61300	2580	1580	17600	8930	3890	5.6	240
ED-82-39	5.65	315	79900	3180	2050	23800	13100	4370	5.7	207
ED-82-40	5.53	315	83300	3890	2390	28400	12800	3680	5.8	225
Maryland_GARCO_G41	3				4980	74400				
Maryland_WASCO_AC2	7				29	77				

Sample/API Number	pH	Li (mg/L)	Na (mg/L)	K (mg/L)	Mg (mg/L)	Ca (mg/L)	Sr (mg/L)	Ba (mg/L)	Mn (mg/L)	Fe (mg/L)
Maryland-153			31500	1320	1040	10800				
NewYork_1			254534	1815	1166	14797				
NewYork_2			46214	1902	8750	74185				
NewYork_3			59280	1848		42700				
NewYork_4			64000	1800	5290	44070				
NewYork_5					6051	48320				
OHIO_12			31486	1998	11785	43549				
OHIO_18			21633	267	10016	29585	338			
OHIO_21			86422	2371	4078	25889	1802			
OHIO_243			51787		6124	26945				
OHIO_244			43409	3903	11207	48584				
OHIO_25			33449	2024	11350	49011	957			
OHIO_2545		167	73800	2260	4040	21000	2100			
OHIO_287			18491	1995	10589	36270	1383			
OHIO_29			35356	828	6690	16726	trace			
OHIO_3			31149	1884	11781	43407				
OHIO_31			32422	1409	11653	43716	1281			
OHIO_32			50460	2097	6835	30844	345			
OHIO_34			31877	2706	11004	44556	1417			
OHIO_3477		173	75000	2050	3790	19000	2060			
OHIO_36			27853	2091	10431	37946	1843			
OHIO_37			32898	2591	9872	41586	1160			
OHIO_38			17568	1003	6578	21619	trace			
OHIO_57			24351	1013	8978	24013	793			
OHIO_58			28689	2250	11442	41244	1645			
OHIO_65-88		141	43300	3990	8720	38600	1730			
OHIO_709		148	48200	4430	10200	43100	2130			
PENN_TULLY_1	6.5	187	42800	3970	8280	37300			1.7	3.9
PENN_TULLY_176	3.95		78700	3400	2400	39300				
PENN_TULLY_177	4.55		74200	3700	2900	46800				
PENN_TULLY_178	5		78700	3500	2400	38500				
PENN_TULLY_179	3.8		47600	1576	1736	21400				
PENN_TULLY_181	4.8		58000	1968	2016	26200				

Sample/API Number	pH	Li (mg/L)	Na (mg/L)	K (mg/L)	Mg (mg/L)	Ca (mg/L)	Sr (mg/L)	Ba (mg/L)	Mn (mg/L)	Fe (mg/L)
PENN_TULLY_183	2.8		54000	1920	520	38597				1830
PENN_TULLY_183a	4.5		70000	2360	2182	48031				2070
PENN_TULLY_185	4.85		73400	3440	3040	44000				
PENN_TULLY_185a	4.9		76000	3440	3040	44400				
PENN_TULLY_186	3.55		19000	2500	2500	36000				
PENN_TULLY_187	3.15		65300	2900	2400	33400				
PENN_TULLY_189	4.9		43600	1704	1856	24400				112
PENN_TULLY_190	5.8		55700	4900	3500	57400				
PENN_TULLY_191	3.03		74200	3300	2800	42500				
PENN_TULLY_192	2.9		55700	4900	3650	54100				
PENN_TULLY_193	6.1		47600	584	1240	10319		1871		
PENN_TULLY_193a	4.3		91000	1160	2267	18409				226
PENN_TULLY_194	4.2		71660	2320	1493	45169				820
PENN_TULLY_195	3.6		60000	1760	1252	36058				2838
PENN_TULLY_196	4.4		66000	2504	3360	38987		640		316
PENN_TULLY_197	4.1		85000	1600	1944	41438				389
PENN_TULLY_198	6.5		45600	576	1075	5920		921		
PENN_TULLY_199	3.9		69600	2304	5019	4967				294
PENN_TULLY_200	5.8		104070	2072	1250	13413				379
PENN_TULLY_201	8.1		195	6	29					
PENN_TULLY_203	3.7		93000	1040	971	11193				220
PENN_TULLY_204	3.5		74400	3344	3840	42000				16.5
PENN_TULLY_205	5.1		64000	2000	8000	36000				
PENN_TULLY_209	5.15		34200	940	1020	12400				
PENN_TULLY_210	3.1		92000	2560	2000	24400				
PENN_TULLY_211	3.2		47400	1360	1296	13200				
PENN_TULLY_212	2.4		94400	2440	1760	20000				
PENN_TULLY_213	4.95		43000	1500	1600	19200				
PENN_TULLY_214	4.2		66000	2400	1920	25000				
PENN_TULLY_215	3.65		76000	2460	1760	26800				
PENN_TULLY_216	3.55		57000	2040	1020	24600				
PENN_TULLY_217	3.2		15520	34	1640	5880				
PENN_TULLY_217a	3.9		34000	1160	1000	10408				

Sample/API Number	pH	Li (mg/L)	Na (mg/L)	K (mg/L)	Mg (mg/L)	Ca (mg/L)	Sr (mg/L)	Ba (mg/L)	Mn (mg/L)	Fe (mg/L)
PENN_TULLY_220a	7.4		47400	176	60	598				
PENN_TULLY_224	5.7		53400	4320	7006	55728				9
PENN_TULLY_225	3.4		73000	2160	2968	25108		2553		274
PENN_TULLY_227	4.4		81000	2960	2134	35438				196
PENN_TULLY_227a	3.7		82200	2960	2087	35096				196
PENN_TULLY_229	5.7		80000	3080	1672	34405				106
PENN_TULLY_3			47400	1276	5790	47300				65
PENN_TULLY_4			57967	3360	4966	49774				124
PENN_TULLY_45	3.03	219	66100	2190	2350	31600	304		0.72	286
PENN_TULLY_5			56176		7806	56004				144
PENN_TULLY_52										
PENN_TULLY_56			47400	1276	5790	47200				71.2
PENN_TULLY_59			64550	5160	2480	25190	3550			160
PENN_TULLY_68	2.65		55000	2780	1250	34700				
PENN_TULLY_69	3.2		56200	3260	3700	38400				
PENN_TULLY_78										
PENN_WEST_1101	2.35		57100	3260	3510	35900				
PENN_WEST_1102	2.65		55000	2780	1250	34700				
PENN_WEST_1103	3.2		56200	3260	3700	38400				
PENN_WEST_1203	6.5	187	42800	3970	8280	37300			1.7	3.9

Sample/API Number	HCO_3 (mg/L)	CO_3(mg/L)	SO_4 (mg/L)	F (mg/L)	Cl (mg/L)	Br (mg/L)	I (mg/L)	SiO_2(mg/L)
3407321971								
3705120737			0		209000			
3711720158			325		236000			
3711720159			0		176500			
4700500567					151000			
4700700226	105		117		151000	880	18	
4700700447								
4701502426			6		143750			
4702300005			0		63000			
4702300007			0		114500			
4702300008			1		14650			
4702300009			0		79200			

Sample/API Number	HCO_3 (mg/L)	CO_3(mg/L)	SO_4 (mg/L)	F (mg/L)	Cl (mg/L)	Br (mg/L)	I (mg/L)	SiO_2(mg/L)
4702300010			0		125000			
4702300011			0		55600			
4702300012			1250		68000			
4702300013			0		121500			
4702300014			0		127500			
4702300015			0		21250			
4702300017			0		100000			
4702300018			0		13700			
4702300019			0		116250			
4702300020			0		102000			
4702300021			0		8000			
4702300023			0		152500			
4702300030			0		50000			
4702300032			120		11000			
4703100016					27900			
4703500022			154		163500	580	16	
4703500024	3		111		161300	2170	23	
4703500041			110		85800	500	8	
4703500053			79		159000	2000	0.8	
4703500077	31		76		164000	1160	9	
4703500094			18		209250			
4703500103	90		86		162000	1025	4	
4703500104			22		57000			
4703500112	118		83		161600	42	18	
4703500198	35		41		170000	1100	20	
4703500223	15		69		107270	440	4	
4703500224			52		146000	250	17	
4703500225			18		196250			
4703500272			34		167500			
4703500273			60		172500			
4703500308			65		146400	1260	23	
4703500312	77		58		163500	830	20	
4703500332			49		147500	1260	23	

Sample/API Number	HCO_3 (mg/L)	CO_3(mg/L)	SO_4 (mg/L)	F (mg/L)	Cl (mg/L)	Br (mg/L)	I (mg/L)	SiO_2(mg/L)
4703500337			62		138300	1600	11	
4703500381			89		162100	830	2	
4703500398			60		164000	1235	8	
4703500413			30		111000			
4703500419			18		212000			
4703500441	5		72		166400	618	11	
4703500486								
4703500512								
4703500531								
4703500911								
4703502408								
4703502464								
4703900222	133		113		143600	850	3.4	
4703900226	100		68		159900	990	Trace	
4703900269	266		62		141400	1532	34	
4703900321	120		46		144800	1380	14	
4703900458			77		161900	750	25	
4703900513			62		163300	1000	21	
4703900696	80		75		150200	1200	Trace	
4703900754	140		93		166700	1800	20	
4703900771			12		215000			
4703900926	140		45		158100	2075	13	
4703901352								
4703901533								
4703905269								
4705300260			220		136000			
4705500014								
4705700022			0		140			
4705900641			0		30000			
4706100337			0		199000			
4706100347			0		193000			
4706900038			220		136000			
4707100010			0		113000			

Sample/API Number	HCO_3 (mg/L)	CO_3(mg/L)	SO_4 (mg/L)	F (mg/L)	Cl (mg/L)	Br (mg/L)	I (mg/L)	SiO_2(mg/L)
4707100012			0		46750			
4707500011			0		18000			
4707500014			0		125000			
4707500025			18		175000			
4707500026								
4707500033								
4707500034			70		28000			
4707700013			125		55000			
4707700021			170		75000			
4707700025					16600			
4707700058			370		160000			
4707700090	0		635		197915			
4707700141			185		20000			
4707700143			100		193000			
4707700155					122000			
4707700156			40		210000			
4707700158			325		80000			
4707700162			78		200000			
4707700164			82		125000			
4707700166			0		157000			
4707700186			0		203000			
4707700316			0		157000			
4707900031					69700			
4707900204	23		53		163200	1700	5	
4708100289								
4708300002	122		900		64000	167	5.7	
4708300096								
4708300097			0		60000			
4708300118			40		87000			
4708300124								
4708300126			37		115000			
4708300612			70		140000			
4708300904					120000			

Sample/API Number	HCO_3 (mg/L)	CO_3(mg/L)	SO_4 (mg/L)	F (mg/L)	Cl (mg/L)	Br (mg/L)	I (mg/L)	SiO_2(mg/L)
4708700239	34		1587		135100	642	5	
4708700413	200		89		168300	100	20	
4708700429			41		166000	2500	13	
4708701200								
4708900005								
4709300002			0		142000			
4709702852			0		157000			
4709900393	30		8		75310			
4710500068	113		119		169200	1245	2.7	
4710500091					172000	1280	18	
4710500171	115		86		158000	1000	8.3	
4710500531	61		180		182500			
4710700306								
4710700336								
4710700346					202400			
4710700351								
ED-82-37	n.d.		2.2	tr.	58900	349	16	
ED-82-38	194		n.d.	tr.	133000	763	35	
ED-82-39	122		1	tr.	174000	1010	52	
ED-82-40	99		n.d.	tr.	207000	1130	44	
Maryland_GARCO_G41					226000			
Maryland_WASCO_AC2					7			
Maryland-153					86300			
NewYork_1					153202			
NewYork_2					173254			
NewYork_3					209800			
NewYork_4					200730			
NewYork_5					206900			
OHIO_12	152		228		162210	1265		101
OHIO_18	231		213		114247	1228		53
OHIO_21	16		95		193105	2086		47
OHIO_243			555		144339	1340		
OHIO_244			207		188390			

Sample/API Number	HCO_3 (mg/L)	CO_3(mg/L)	SO_4 (mg/L)	F (mg/L)	Cl (mg/L)	Br (mg/L)	I (mg/L)	SiO_2(mg/L)
OHIO_25	219		219		174137	2024		55
OHIO_2545					174000	1520	26	
OHIO_287			217		126768	1324		20
OHIO_29	116		778		104460	613		5
OHIO_3	176		352		160592	1181		100
OHIO_31	128		359		164519	589		5
OHIO_32	5		469		154984	592		10
OHIO_34	129		232		163846	1881		8
OHIO_3477					169000	1540	27	
OHIO_36	2		337		142591	1619		7
OHIO_37	25		123		156767	1654		12
OHIO_38	53		548		85341	936		3
OHIO_57	169		338		108017	793		51
OHIO_58	97		121		155372	847		48
OHIO_65-88					174000	1870	17	
OHIO_709					195000	1900	19	
PENN_TULLY_1			528	2.3	157000	10600	32	5020
PENN_TULLY_176			10		200602	1860		
PENN_TULLY_177			20		208040	2240		
PENN_TULLY_178			10		198947	1580	5	
PENN_TULLY_179					117301	1032		
PENN_TULLY_181					142265	1095	5	
PENN_TULLY_183					158313			
PENN_TULLY_183a					204925	1020	21	
PENN_TULLY_185					202560	1050	8.6	
PENN_TULLY_185a					207277	1056	9	
PENN_TULLY_186	34		100		148062	1500	8	
PENN_TULLY_187	16		100		168666	1520	7	
PENN_TULLY_189	28				117151	930	4	
PENN_TULLY_190	76		20		201120	2120	7	
PENN_TULLY_191			100		200059	1460	10	
PENN_TULLY_192	33		100		196389	640	19	
PENN_TULLY_193	14				96421	980	54	

Sample/API Number	HCO_3 (mg/L)	CO_3(mg/L)	SO_4 (mg/L)	F (mg/L)	Cl (mg/L)	Br (mg/L)	I (mg/L)	SiO_2(mg/L)
PENN_TULLY_193a					179028	4050	105	
PENN_TULLY_194					197701	1440	10	
PENN_TULLY_195					166674	690		
PENN_TULLY_196					183185	850	12	
PENN_TULLY_197					193986	780		
PENN_TULLY_198					84476	960	45	
PENN_TULLY_199					196249	1500	13	
PENN_TULLY_200	19		160		190528	1260	18	
PENN_TULLY_201	173				289			
PENN_TULLY_203					166847	810		
PENN_TULLY_204					202181	1740	11	
PENN_TULLY_205	10		1		134000			
PENN_TULLY_209			20		78479	32		
PENN_TULLY_210					192880	672	36	
PENN_TULLY_211					101226	525		
PENN_TULLY_212					187479	1260	32	
PENN_TULLY_213					106185	276		
PENN_TULLY_214					153452	732	25	
PENN_TULLY_215					172490	900	44	
PENN_TULLY_216					136101	330	4	
PENN_TULLY_217					391540			
PENN_TULLY_217a					76636	384		
PENN_TULLY_220a	329		231		74027	200		
PENN_TULLY_224					205023	660	16	
PENN_TULLY_225					168779	1100	22	
PENN_TULLY_227					194171	1020	30	
PENN_TULLY_227a					197627	780	40	
PENN_TULLY_229					190808	2760	40	
PENN_TULLY_3			2		172500	70	1	
PENN_TULLY_4			194		198790			
PENN_TULLY_45				21	166000	1060	13	23
PENN_TULLY_5			166		208078			
PENN_TULLY_52					212700			

Sample/API Number	HCO_3 (mg/L)	CO_3(mg/L)	SO_4 (mg/L)	F (mg/L)	Cl (mg/L)	Br (mg/L)	I (mg/L)	SiO_2(mg/L)
PENN_TULLY_56			2		172300	580		
PENN_TULLY_59			50		161800	700		
PENN_TULLY_68					154000	1260	56	
PENN_TULLY_69					170000	1400	23	
PENN_TULLY_78					185000			
PENN_WEST_1101					169000	1440	8.6	
PENN_WEST_1102					154000	1260	5.6	
PENN_WEST_1103					170000	1400	23	
PENN_WEST_1203	176		528	2.3	161000	1770	32	

Source: A—Ohio Stat Division of Natural Resources website http://www.dnr.state.oh.us
B—West Virginia Geologic and Economic Survey website http://www.wvgs.wvnet.edu
C—Chesapeake Energy
D—Kelley, D.R., et al., 1973
E—Poth, C.W., 1962
F—Dresel, P.E., 1985
G—Stout, W., et al., 1932
H—Hoskins, H.A., 1947
I—Price, P.H., et al., 1937
J—Lloyd O.B. and Reid, M.S., 1990
K—NiSource Incorporated.
L—NatCarb website http://www.natcarb.org
M—Woll, R.S., 1978
*--New study data

All data used in this study are available on the West Virginia GIS Technical Center website http://wvgis.wvu.edu.

Appendix IV

Oriskany Sandstone Density Data.

Oriskany Sandstone density data.

Sample/API Number	Horizon	Latitude	Longitude	GL Elevation (m)	Depth/Top (m)	TDS Calculated (mg/L)	Density (kg/m^3)
3711720158	Oriskany	41.76024	-76.99193	522	2038	385500	1308.0
3711720159	Oriskany	41.45374	-76.59301	523	2039	277375	1207.5
4700700226	Oriskany	38.68439	-80.82756	352	1914	246819	1182.8
4700700447	Oriskany	38.79923	-80.55487	269	2101	80000	1045.6
4701502426	Oriskany	38.38474	-81.25295	436	1900	222949	1162.3
4702300005	Oriskany	39.04240	-79.28571	912	2525	102548	1058.5
4702300007	Oriskany	38.95471	-79.32992	825	2563	187404	1124.5
4702300008	Oriskany	39.12748	-79.24653	796	2448	23908	1000.7
4702300009	Oriskany	38.96604	-79.32082	834	2508	128344	1078.3
4702300010	Oriskany	38.14823	-79.23740	805	2504	204038	1138.7
4702300011	Oriskany	39.18613	-79.21765	879	2716	90079	1046.9
4702300012	Oriskany	39.08072	-79.26823	815	2524	110545	1064.6
4702300013	Oriskany	39.09597	-79.27809	904	2650	197705	1131.6
4702300014	Oriskany	39.11528	-79.25558	645	2319	207709	1144.3
4702300015	Oriskany	39.05692	-79.27511	765	2423	35011	1009.3
4702300017	Oriskany	39.02178	-79.29464	868	2582	163637	1105.4
4702300018	Oriskany	39.06824	-79.26191	698	2376	22236	1000.5
4702300019	Oriskany	39.26119	-79.18189	959	2973	188919.3	1121.0
4702300020	Oriskany	39.07332	-79.29409	1055	2830	166400	1104.7
4702300021	Oriskany	39.07782	-79.25428	611	2381	13091	993.8
4702300023	Oriskany	39.10715	-79.26953	829	2557	249278	1175.9
4702300030	Oriskany	39.28557	-79.15300	814	2833	83778	1041.2
4702300032	Oriskany	39.09612	-79.24944	596	2359	17594	998.5
4703500022	Oriskany	38.69528	-81.54256	296	1677	266694	1203.0
4703500024	Oriskany	38.65926	-81.54996	300	1659	266019	1203.1
4703500041	Oriskany	38.59932	-81.63977	200	1512	138199	1096.9

Sample/API Number	Horizon	Latitude	Longitude	GL Elevation (m)	Depth/Top (m)	TDS Calculated (mg/L)	Density (kg/m^3)
4703500053	Oriskany	38.57157	-81.59830	254	1555	259914	1199.0
4703500077	Oriskany	38.57535	-81.64983	288	1592	268146	1205.7
4703500094	Oriskany	38.60634	-81.65371	213	1509	338377	1272.0
4703500103	Oriskany	38.94282	-81.58816	204	1546	264713	1203.3
4703500104	Oriskany	38.60925	-81.62882	276	1586	92342	1059.9
4703500112	Oriskany	38.95341	-81.62567	211	1523	262276	1201.1
4703500198	Oriskany	38.86180	-81.61973	211	1644	275968	1212.0
4703500223	Oriskany	38.82898	-81.61559	195	1532	175678	1126.8
4703500224	Oriskany	38.61543	-81.58049	208	1543	239231	1180.8
4703500225	Oriskany	38.61878	-81.64038	234	1536	315133	1249.3
4703500272	Oriskany	38.74753	-81.63530	256	1579	270117	1207.5
4703500273	Oriskany	38.74394	-81.64003	269	1589	278947	1215.4
4703500308	Oriskany	38.91959	-81.60821	235	1579	239793	1180.7
4703500312	Oriskany	38.79386	-81.61874	213	1549	267695	1206.0
4703500332	Oriskany	38.86413	-81.59392	213	1597	241390	1182.1
4703500337	Oriskany	38.91623	-81.61323	285	1628	226768	1168.7
4703500381	Oriskany	38.63067	-81.64995	248	1561	264309	1203.0
4703500398	Oriskany	38.78094	-81.62115	273	1610	267683	1205.3
4703500413	Oriskany	38.77699	-81.62970	303	1625	178745	1128.2
4703500419	Oriskany	38.76065	-81.64656	190	1503	342271	1275.7
4703500441	Oriskany	38.75161	-81.62059	253	1590	270323	1207.7
4703900222	Oriskany	38.27818	-81.50221	345	1550	238989	1180.6
4703900226	Oriskany	38.43875	-81.35657	382	1761	262164	1198.3
4703900269	Oriskany	38.26830	-81.50828	405	1600	233580	1175.3
4703900321	Oriskany	38.44919	-81.57264	280	1523	271551	1209.4
4703900458	Oriskany	38.44615	-81.58850	305	1561	264280	1202.9
4703900513	Oriskany	38.45065	-81.59200	315	1569	266696	1204.4
4703900696	Oriskany	38.52934	-81.66645	261	1539	253625	1193.5

Sample/API Number	Horizon	Latitude	Longitude	GL Elevation (m)	Depth/Top (m)	TDS Calculated (mg/L)	Density (kg/m^3)
4703900754	Oriskany	38.47315	-81.44838	223	1589	273093	1210.1
4703900771	Oriskany	38.56897	-81.64680	232	1537	347133	1279.5
4703900926	Oriskany	38.45166	-81.65561	217	1478	259923	1199.7
4705700022	Oriskany	39.40201	-79.04544	585	2609	222	981.8
4705900641	Oriskany	37.63161	-81.87895	350	1657	48245	1026.1
4706100337	Oriskany	39.58848	-79.83815	608	2471	279860	1203.8
4706100347	Oriskany	39.56573	-79.88614	626	2446	271200	1196.2
4706900038	Oriskany	40.05866	-80.58205	396	2060	216847	1155.1
4707100010	Oriskany	38.91014	-79.34745	769	2594	185867	1122.6
4707100012	Oriskany	38.79632	-79.42260	824	2458	76479	1039.4
4707500011	Oriskany	38.67495	-79.75759	1052	1750	28441	1010.6
4707500014	Oriskany	38.63024	-79.78072	984	1815	195659	1140.5
4707500025	Oriskany	38.68381	-79.75481	1048	1771	282995	1216.2
4707500034	Oriskany	38.66769	-79.76184	1063	1806	56058	1030.6
4707700013	Oriskany	39.43387	-79.57246	656	1649	89348	1057.1
4707700021	Oriskany	39.41043	-79.57720	685	1630	122512	1082.9
4707700058	Oriskany	39.40331	-79.59137	536	1419	259414	1199.9
4707700090	Oriskany	39.35337	-79.60835	784	1835	321954	1242.7
4707700141	Oriskany	39.38034	-79.58653	610	1609	30887	1013.7
4707700143	Oriskany	39.36482	-79.60156	680	1651	313023	1245.9
4707700155	Oriskany	39.38197	-79.58294	610	1603	198626	1245.9
4707700156	Oriskany	39.37754	-79.59483	631	1568	340920	1272.8
4707700158	Oriskany	39.36237	-79.59397	775	1810	130370	1087.5
4707700162	Oriskany	39.35409	-79.62037	617	1611	324460	1257.3
4707700164	Oriskany	39.33534	-79.62316	794	1953	202318	1144.2
4707700166	Oriskany	39.42145	-79.54762	815	2010	255943	1189.4
4707700186	Oriskany	39.51110	-79.83121	540	2368	292200	1216.2
4707700316	Oriskany	39.53456	-79.85094	566	2358	255943	1184.4

Sample/API Number	Horizon	Latitude	Longitude	GL Elevation (m)	Depth/Top (m)	TDS Calculated (mg/L)	Density (kg/m^3)
4707900204	Oriskany	38.61311	-81.74124	272	1547	266039	1204.5
4708300002	Oriskany	38.78442	-79.91600	619	1135	107840	1076.1
4708300097	Oriskany	38.81316	-79.67742	903	1608	97453	1063.8
4708300118	Oriskany	38.78203	-79.69855	987	1516	136876	1095.3
4708300126	Oriskany	38.79111	-79.69454	985	1601	185113	1134.1
4708300904	Oriskany	38.62224	-79.88941	1131	2503	191039	1128.0
4708700239	Oriskany	38.61978	-81.14033	314	1822	222755	1162.7
4708700413	Oriskany	38.55924	-81.39392	309	1676	275327	1210.8
4708700429	Oriskany	38.60787	-81.51940	207	1544	272738	1210.5
4709300002	Oriskany	39.06310	-79.40547	1019	2515	230964	1161.1
4709702852	Oriskany	38.69745	-80.28997	812	2370	253721	1182.5
4709900393	Oriskany	38.23142	-82.55329	231	928	121699	1088.9
4710500068	Oriskany	38.99318	-81.30763	254	1494	273600	1212.0
4710500068	Oriskany	38.99318	-81.30763	254	1494	274294	1212.6
4710500171	Oriskany	38.91115	-81.36267	246	1724	255999	1192.9
4710500531	Oriskany	38.95428	-81.29141	320	1807	294197	1226.3
4710700351	Oriskany	39.25698	-81.27240	324	1323	190000	1141.0
ED-82-37	Oriskany	39.97139	-79.09139	646	2694	101000	1055.2
ED-82-38	Oriskany	39.94111	-79.11944	570	2676	230000	1158.3
ED-82-39	Oriskany	39.93361	-79.11056	642	2697	302000	1219.6
ED-82-40	Oriskany	40.04167	-78.91667	718	2604	343000	1258.1
OHIO_12	Oriskany	40.85057	-82.08988	357	652	252900	1203.1
OHIO_21	Oriskany	40.40286	-80.71155	357	1568	316100	1249.5
OHIO_243	Oriskany	40.91527	-81.76897	290	693	231090	1183.0
OHIO_287	Oriskany	41.32416	-81.53710	347	753	197550	1153.3
OHIO_29	Oriskany	40.74705	-82.40302	347	611	165600	1127.6
OHIO_3	Oriskany	40.92303	-82.14164	337	608	251200	1202.1
OHIO_31	Oriskany	41.26723	-81.95789	255	463	256100	1208.2
OHIO_32	Oriskany	41.15853	-81.64475	318	650	246750	1197.5

Sample/API Number	Horizon	Latitude	Longitude	GL Elevation (m)	Depth/Top (m)	TDS Calculated (mg/L)	Density (kg/m^3)
OHIO_34	Oriskany	41.16371	-81.99154	270	530	257700	1209.1
OHIO_36	Oriskany	41.01102	-82.11317	332	555	224800	1179.0
OHIO_57	Oriskany	41.40439	-82.09609	191	337	168750	1132.4
OHIO_58	Oriskany	41.19994	-82.01069	282	475	241900	1195.3
OHIO_65-88	Oriskany	41.90777	-80.73238	190	494	284900	1234.1
OHIO_709	Oriskany	41.82107	-81.00393	205	497	319500	1266.8
PENN_TULLY_1	Oriskany	42.07306	-80.06202	272	609	272518	1221.5
PENN_TULLY_176	Oriskany	41.03091	-78.84634	450	2213	327262	1250.3
PENN_TULLY_177	Oriskany	41.05477	-78.75641	485	2213	338440	1260.6
PENN_TULLY_178	Oriskany	41.12063	-78.74281	460	2189	324112	1247.4
PENN_TULLY_179	Oriskany	41.23796	-78.62943	533	2241	191311	1131.4
PENN_TULLY_181	Oriskany	41.23262	-78.53979	478	2188	232255	1166.2
PENN_TULLY_183	Oriskany	40.84483	-78.44819	526	2440	253770	1181.2
PENN_TULLY_183a	Oriskany	40.84483	-78.44819	526	2449	330389	1249.0
PENN_TULLY_185	Oriskany	41.06146	-78.81391	472	2270	328338	1250.5
PENN_TULLY_185a	Oriskany	41.06146	-78.81391	472	2211	336042	1258.4
PENN_TULLY_186	Oriskany	41.21724	-78.53979	352	2089	240329	1174.5
PENN_TULLY_187	Oriskany	41.07349	-78.73435	512	2257	274977	1202.5
PENN_TULLY_189	Oriskany	41.07884	-78.72566	487	2207	190401	1131.2
PENN_TULLY_190	Oriskany	41.08218	-78.71630	471	2205	325408	1248.6
PENN_TULLY_191	Oriskany	41.04140	-78.77714	443	2198	325054	1248.3
PENN_TULLY_192	Oriskany	41.05343	-78.81325	450	2212	316299	1240.2
PENN_TULLY_193	Oriskany	39.82755	-78.35384	331	1402	159797	1115.4
PENN_TULLY_193a	Oriskany	39.82755	-78.35384	331	1437	297592	1234.5
PENN_TULLY_194	Oriskany	40.79758	-78.99555	423	2199	319848	1243.5
PENN_TULLY_195	Oriskany	41.38039	-78.33475	516	2089	268721	1199.1
PENN_TULLY_196	Oriskany	40.85196	-79.01606	479	2323	297265	1221.5
PENN_TULLY_197	Oriskany	41.40103	-78.28866	423	2014	325009	1251.5

Sample/API Number	Horizon	Latitude	Longitude	GL Elevation (m)	Depth/Top (m)	TDS Calculated (mg/L)	Density (kg/m^3)
PENN_TULLY_198	Oriskany	39.76393	-78.38837	333	1515	139277	1097.2
PENN_TULLY_199	Oriskany	40.87603	-78.89214	612	2306	279698	1205.9
PENN_TULLY_200	Oriskany	40.62273	-79.41129	324	2349	303654	1226.4
PENN_TULLY_203	Oriskany	41.16105	-78.67281	501	2259	274542	1202.1
PENN_TULLY_204	Oriskany	41.06213	-78.73168	449	2187	330058	1252.9
PENN_TULLY_205	Oriskany	41.03781	-78.78422	429	2214	250203	1181.6
PENN_TULLY_209	Oriskany	40.10795	-79.06582	629	2566	127477	1077.0
PENN_TULLY_210	Oriskany	40.09538	-79.29357	666	2236	315328	1238.6
PENN_TULLY_211	Oriskany	40.09686	-79.07691	647	2594	154357	1097.5
PENN_TULLY_212	Oriskany	40.10647	-79.28839	747	2383	308131	1230.4
PENN_TULLY_213	Oriskany	40.11756	-79.05325	637	2341	172401	1114.7
PENN_TULLY_214	Oriskany	40.12865	-79.04215	621	2615	250199	1176.0
PENN_TULLY_215	Oriskany	40.06506	-79.09540	628	2579	281474	1203.7
PENN_TULLY_216	Oriskany	40.09168	-79.11018	621	2601	220885	1151.4
PENN_TULLY_217	Oriskany	40.16341	-79.14050	753	2477	414614	1328.6
PENN_TULLY_217a	Oriskany	40.16341	-79.14050	753	2455	124060	1075.5
PENN_TULLY_220a	Oriskany	40.00221	-79.33054	843	2470	122695	1074.4
PENN_TULLY_224	Oriskany	41.35134	-80.19413	404	1219	330382	1268.1
PENN_TULLY_225	Oriskany	40.32857	-79.26270	824	2298	277677	1204.1
PENN_TULLY_227	Oriskany	40.22254	-79.38544	640	2539	317284	1235.5
PENN_TULLY_227a	Oriskany	40.22254	-79.38544	640	2539	321308	1239.1
PENN_TULLY_229	Oriskany	40.38876	-78.82247	650	2697	312823	1229.2
PENN_TULLY_3	Oriskany	41.91240	-77.17413	482	1315	276234	1216.4
PENN_TULLY_4	Oriskany	41.67769	-79.39847	500	1321	309560	1247.0
PENN_TULLY_45	Oriskany	40.17965	-79.43499	540	2236	272298	1200.1
PENN_TULLY_5	Oriskany	41.45388	-80.36174	302	977	332297	1273.4
PENN_TULLY_52	Oriskany	41.36045	-77.91030	309	1841	345000	1272.7
PENN_TULLY_56	Oriskany	41.91516	-77.16770	482	1315	278048	1218.0

Sample/API Number	Horizon	Latitude	Longitude	GL Elevation (m)	Depth/Top (m)	TDS Calculated (mg/L)	Density (kg/m^3)
PENN_TULLY_59	Oriskany	40.41272	-80.31738	320	1908	264835	1198.6
PENN_TULLY_68	Oriskany	41.06012	-78.72298	456	2215	248511	1180.1
PENN_TULLY_69	Oriskany	41.14331	-78.61464	502	2296	274763	1201.5
PENN_TULLY_78	Oriskany	40.20258	-79.40985	573	2258	302000	1226.5
PENN_WEST_1101	Oriskany	41.17930	-78.60232	495	2246	312000	1235.5
PENN_WEST_1102	Oriskany	41.07578	-78.71878	456	2215	279000	1206.7
PENN_WEST_1103	Oriskany	41.16474	-78.61849	502	2295	311000	1233.8
PENN_WEST_1203	Oriskany	42.07863	-80.08718	272	609	256000	1206.4
4703905269	Oriskany	38.44251	-81.40303	368	1706	129349	1087.7
4703901533	Oriskany	38.44865	-81.43750	307	1654	92283	1059.4
4707500026	Oriskany	38.66391	-79.76351	1072	1794	21691	1005.2
4707500033	Oriskany	38.65999	-79.76554	1014	1740	37090	1017.0
4708300124	Oriskany	38.74918	-79.72155	1061	1624	1836	992.0
4708300096	Oriskany	38.75422	-79.72298	990	1572	3622	993.7
4703901352	Oriskany	38.52411	-81.48586	260	1581	51230	1028.8
4703500486	Oriskany	38.88430	-81.68152	201	1481	55722	1033.0
4703500911	Oriskany	38.88024	-81.69545	223	1498	99380	1066.3
4703500531	Oriskany	38.85337	-81.69466	225	1504	148323	1105.0
4703500512	Oriskany	38.83755	-81.67890	208	1502	217147	1162.2
4703502408	Oriskany	38.82390	-81.68112	225	1512	202822	1150.1
4703502464	Oriskany	38.84409	-81.69855	184	1462	82199	1053.0
4710700336	Oriskany	39.07782	-81.53571	300	1598	226438	1169.1
4710700306	Oriskany	39.05808	-81.55022	329	1640	222516	1165.1
3407321971	Oriskany	39.51075	-82.55570	340	665	194292	1151.4